Solar Evaporation of Liquid Effluent from Composting Toilets in Cool Temperate Climates

by

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference is made in the text of the thesis.

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Abstract

This thesis investigates the design of a solar powered evaporator aimed at reducing visual intrusion of composting toilet infrastructure on the natural landscape.
A series of tests were undertaken beginning in the laboratory, progressing to outdoor conditions at the University of Tasmania in Hobart and culminating in a field test in the Mt Field National Park in southern Tasmania. This field test involved the substitution of the field test evaporator for an existing unit at the Government Huts composting toilet facility. A method for gathering the data to enable matching of evaporator size to effluent output rate was also evaluated.

The performance related objectives were realized by increasing evaporative efficiency over the existing National Parks and Wildlife Service (NPWS) design and achieving flexibility in siting through good evaporative performance in cold and diffuse light conditions. Over a twelve month period of operation in an alpine location the 1.5m x 1.5m solar evaporator dealt with all the liquid effluent from two public composting toilets. A method for gathering the necessary empirical evidence to properly match evaporator size to toilet loading was also tested at Mt Field resulting in the calculation of average figures for the volume of liquid expelled to the evaporator per toilet use.

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CHAPTER 1

Introduction

Tasmania is an island state of Australia located at latitude S 42° on the eastern end of the southern coast of the main continent. It exhibits a cool temperate climate and is revered by bushwalkers the world over for its ecological uniqueness resulting from isolation and for the beautiful wilderness experiences possible as a result of the World Heritage Areas and National Parks preserving some ecosystems in a "natural" state. Tasmania is confronted, like many similar locations, with the prospect of increasing bushwalker numbers causing damage to both the environment and the wilderness experience. Walks such as the Overland Track in the Cradle Mountain – Lake St.Clair National Park are famous and hugely poplar with interstate and international bushwalkers, especially in summer. 8169 registered individuals walked the Overland Track over the 2002/3 financial year depositing approximately 7300kg of faecal waste and 59000L of urine into the park (See Appendix A). Even the most isolated of campsites now attract sufficient numbers of overnight visitors to require toilet infrastructure.

Appropriately selected campsites provide year round access to drinking water in reasonable proximity to camping and cooking areas. Unfortunately, as a result of this, along with the pleasant memories of trekking through remote and beautiful terrain, many bushwalkers take away less congenial memories of Tasmania relating to the symptoms of gastrointestinal disease contracted through drinking surface water contaminated by pathogens derived from human faeces. These pathogens find their way into drinking water when toilet technology fails, when insufficient maintenance is carried out, or when the guidelines for safe bush toilet practice are inappropriate or simply not followed. Gastrointestinal disease is the main anthropocentric risk associated with the escape of effluent from toilets, while ecologically related problems include damage to sensitive, low-nutrient adapted native vegetation and the increased propensity for the infiltration of high-nutrient adapted exotic plant species.

In order to cope with increasing loads of human effluent in popular Tasmanian bushwalking destinations, several variants on "built" toilet infrastructure have been trialled by the Tasmanian National Parks and Wildlife Service (NPWS). Long drops (a toilet pedestal located above a deep pit) are common, and quite satisfactory for some soil types and topography; closed system toilets emptied via helicopter have been used in remote areas, but have resulted in high maintenance costs; composting toilets appear to be the preferred solution where ecosystems are sensitive, however studies such as those conducted by Crennan (1995) have proven that many composting toilets do not function properly. At the time of her investigation of 24 Tasmanian composting toilets located in parks throughout the state, 16 were not composting, while the remainder were only partially doing so.

The suitability of composting toilets for use in the cool temperate climatic conditions encountered in Tasmania is dependent on two main factors: the capture and retention of sufficient heat for microbial breakdown of compost; and the removal of excess liquid effluent via evaporation. While composting toilets in warmer climates have few problems with excess liquid, their function in cool temperate conditions is often associated with this affliction. This is further exacerbated in Tasmanian circumstances where many popular bushwalks are located in highland areas that experience lower temperatures than those encountered at sea level. In such conditions, the cool temperatures and high humidity combine to inhibit the process of evaporation. This can cause saturation of the compost pile through a build up of liquid effluent limiting the oxygen available for aerobic breakdown of the solids contained therein. This saturation, combined with the cold highland conditions, can slow or halt the composting process. Even in conditions where enough heat is generated by the pile, or retained from passive solar heat uptake, saturation will lead to anaerobic breakdown and the emission of unpleasant odours such as those associated with the production of ammonia. In addition, a build up of liquid effluent in such conditions can lead to overflow into the surrounding environment. The Tasmanian NPWS have trialled evaporation methods for removing this effluent but are currently utilising evaporators that are visually obtrusive and impractical for remote sites due to their size.

The challenge of dealing with liquid effluent in this context, and in a way that is conducive to upholding the values associated with both wilderness preservation and the wilderness experience are central to this thesis. Moreover, due to the remote conditions in which these toilets often operate, a low maintenance and minimal visual intrusion approach has been deemed essential.

1.1 AIM OF THIS STUDY

This thesis aims to investigate the possibility of designing a more efficient evaporator capable of working in shaded or overcast conditions in the Tasmanian highlands. Such a design would enable reduction of visual intrusion of toilet infrastructure on the natural landscape in two ways through greater flexibility in siting (i.e. amongst trees in locations where the topography and vegetation allows), and via the use of smaller evaporation units, made possible through a more efficient design.

This thesis also examines the potential for proper matching of evaporator size to the visitation demands of an area to further reduce visual intrusion. This involves the collection of data relating to toilet user numbers and the subsequent liquid effluent outflow to an evaporator attached to a Tasmanian NPWS designed composting toilet.

Finally, it is suggested that adaptation of appropriate composting toilet designs to these conditions via the use of an enhanced evaporation process will make for the best human waste solution for Tasmanian highland ecosystems.

"By isolating, containing, and composting fresh human excreta, composting toilets offer the potential for a significant, effective, on-site barrier between any excreted pathogenic organism and the human host" (Berry, 2000, p.90). Subsequently, if the effluent overflow problem associated with composting toilet use in cool climates is abated the human and animal health issues and nutrient concentration problems can be eliminated.

Work has already been carried out to address the lack of microbial activity in situations where solids contained in these toilets become cold (see Dickson, 2000).

The aims of this study have resulted in the formation of two research questions:

> Can the current NPWS evaporator design be replaced with a design that facilitates increased efficiency leading to reduced size and visual intrusion?
>
> Can empirical evidence be gathered and processed in order to properly match evaporator size to toilet loading?

In order to address these questions the removal of liquid toilet effluent via solar enhanced evaporation has been investigated with the intention of increasing the efficiency of evaporator design. Data gathering techniques have been employed to provide empirical evidence for matching this new, modular design to the predicted toilet usage and climatic conditions encountered at various toilet sites.

1.2 OBJECTIVES

1.2.1 OBJECTIVE ONE

Conduct basic laboratory testing and a literary review for facilitating a greater understanding of the various aspects of evaporation and to identify the key considerations for liquid human waste management in remote cool temperature areas of Tasmania.

1.2.2 OBJECTIVE TWO

Apply these basic principles and the results from laboratory testing to the design and construction of a prototype evaporator. Following this, conduct a testing regime involving the prototype tested against a control designed to simulate the performance of the existing National Parks and Wildlife Evaporators.

1.2.3 OBJECTIVE THREE

Use the results from testing and observation to design and construct a final evaporator for testing in the field. Also, gather empirical evidence in the field to better enable the matching of toilet loads to evaporator size.

1.3 THESIS STRUCTURE

Chapter one provides an introduction to the context of this thesis and outlines the research questions and objectives.

Chapter two presents a more detailed reasoning for this research and examines the theoretical basis to the problems associated with the escape of liquid effluent from toilet facilities. Also, chapter two presents the idea that minimal visual intrusion is a key consideration in this area of research. An examination of evaporation theory, the properties of water and the potential for disease transmission through the production of bioaerosols is then provided.

Chapter three examines the four phases of testing employed in the design of this solar evaporator for preventing the escape of liquid toilet waste and presents results from the scientific analysis of evaporation and its properties in the laboratory.

Chapter four presents the results from prototype and field test evaporator testing at the University of Tasmania followed by the results gathered from testing the final design in the field.

Chapter five provides a discussion of the findings of those results presented in chapter four and further examination of the ramifications of the aerobiolgical risks associated with this endeavour.

Chapter six provides a conclusion to the thesis by revisiting the research questions and objectives, examining limitations and suggesting areas for further investigation.

CHAPTER 2

Literature Review

> *At best, our few remaining wild areas offer us the opportunity to withdraw and recreate, to rekindle our bond with the spirit of the land. At the very least their presence reminds us this bond continues to exist and remains manifest in wild and remote places.*
>
> *Yet while a complex range of diverse pressures is being applied to the environment, it is ironic that our increasing need for recreation and relief, if poorly managed, can lead to its very exhaustion and destruction.*
> (Bzowy, 1989, p.99)

2.1 INTRODUCTION

Increasing visitation to Tasmanian natural areas such as nature reserves, National Parks and private lands dedicated to tourism and recreation activities places pressure on the natural environment. Toilet facilities are now necessary in extremely remote camping areas in Tasmania, providing challenging conditions in which to manage effluent.

The selection of remote campgrounds and hut sites is usually based on the proximity to a reliable water source. It is imperative to avoid contamination of surface and ground water with human effluent at these locations as they are used for human consumption. Appropriate toilet facilities employ measures to prevent both effluent overflow and disease transmission via insect and mammalian vectors; the latter being relevant because otherwise the practice of sourcing drinking water upstream of toilets does not guarantee safe supply.

The geographical location of many remote Tasmanian huts and campsites presents a special challenge in managing human effluent due to local cool temperate climatic conditions. For example, the popular Central Plateau camping areas at an elevation of around 800m experience average minimum temperatures of between approximately 0°C in winter and 6°C in summer. These conditions are not conducive to evaporation and can lead to excess build up of liquid toilet effluent and subsequent negative impacts on local flora and fauna as well as the aforementioned anthropocentric outcomes (Holman and Todd, 2001).

This chapter provides a brief history of the methods employed for human waste management in remote areas of Tasmania and then critically examines the problems associated with human faecal contamination of ecologically sensitive areas, existing solutions to these problems and the theoretical basis to the work presented in this thesis.

2.2 THE VARIOUS METHODS OF HUMAN WASTE MANAGEMENT EMPLOYED IN REMOTE AREAS OF TASMANIA

Various methods of managing human waste in remote areas of Tasmania have been employed including cat holes, pit toilets, fly-out tanks and composting toilets. These are examined below.

2.2.1 CAT HOLES

The use of what is known as a cat hole, to dispose of human faecal waste, has been recommended by the Tasmanian NPWS in areas where no toilet facilities are provided. This method involves selecting a site at least 100m from a watercourse and digging a hole 15cm deep to bury faecal waste and toilet paper (Parks and Wildlife Service Tasmania, 2000). When executed correctly the cat hole approach removes human faecal matter and toilet paper from sight and decreases the chance of insect or mammalian transmission of the pathogens associated with such waste relative to disposal on the surface. The mechanical disturbance created through this method, though exhibiting negative effects on the growth on some native plant species has been deemed of little conservation significance in itself (Bridle and Kirkpatrick, 2003).

However, this method can prove impossible to execute in areas with shallow soils and finding a location at the recommended distance from a watercourse can prove extremely difficult in many areas of highland Tasmania due to the wide distribution of streams and tributaries (Dickson, 2000). Even where this is possible, the desire for privacy often overrides that of meeting the cat hole guidelines, resulting in an area with adequate tree or vegetation cover being selected over a more appropriate location (Brassington, 1999). When cat hole sites are selected in close proximity to watercourses and campsites surface water becomes contaminated with human faecal matter. Furthermore, in certain locations with wet, organic and/or highly acidic soils the breakdown of the faecal matter is very slow, increasing the likelihood of long term surface water contamination and a build up of human waste (Kirkpatrick, 2002). Finally, cat holes can prove inadequate at mitigating mammalian or insect transmission of human waste related pathogens due to excavation and consequent direct dispersal or zoonotic dispersal via consumption of faecal matter.

2.2.2 PIT TOILETS

A pit toilet consists of a hole, typically two metres deep and two metres wide, over which a wooden platform and pedestal are placed. This type of toilet has been used extensively throughout Tasmania with varying success. Such toilets work better where soil drainage is good; poor drainage results in a build up of human waste due to low levels of absorption requiring new pits to be dug on a regular basis.

These toilets provide no isolation of human faecal waste from the natural environment and are inappropriate where increased nutrient levels, contamination of drinking water, or site disturbances are undesirable. The use of pit toilets results in contamination of surface and groundwater and transfer of both nutrients and pathogens to the local environment (Nichols, Prettyman and Gross, 1983). Pit toilets are unsuitable for use in alpine conditions because breakdown of the faecal matter, toilet paper and tampons deposited therein is extremely slow (Bridle and Kirkpatrick, 2005). Also, these facilities are notoriously odorous at times of high usage often resulting in the adoption of a cat hole approach in close proximity to the pit toilet.

2.2.3 FLY OUT TANKS

Fly out tanks are used in areas of low tourist or recreational usage (less than 250 visitors per year) such as the Walls of Jerusalem National Park and the Arthur Pieman Protected Area. They consist of a tank with a screw cap that is removed to use the toilet and replaced afterwards. They are usually about 450 litres in capacity and gain their name from the extraction process using a helicopter to replace and remove the tank when it is full. In theory these tanks isolate the effluent from the local environment, provide safe handling during extraction and cost approximately $4000 plus $1000 per helicopter removal (Dickson, 2000).

In practice this method has some negative aspects and horror stories abound amongst bush walkers and NPWS workers alike of removing overflowing tanks or enduring disgusting splash back experiences while defecating in the not too private circumstances dictated by toilet location and design. This would suggest that at times visitors would be inclined to use a cat hole approach in the vicinity, thus contributing to contamination of the surrounding area with human waste. Another contributing factor is that of overflow caused either by failure to replace the lid resulting in rainwater accumulating to overflow point, or where the tanks are not replaced at appropriate intervals.

2.2.4 A CARRY OUT APPROACH

In some camping areas with low user numbers and no toilet facilities visitors are advised to carry out their toilet waste either in a specifically designed device or using several strong plastic bags (Brauns, 2000). This has the potential to reduce contamination of drinking water due to the isolation of human waste from the environment. Some, if not many, campers may take offence to having to deal so directly with their waste and accordingly, the success of this method depends on user acceptance. Again, failure to comply with guidelines to carry out waste may lead to the local environment becoming contaminated with faecal matter.

2.2.5 COMPOSTING TOILETS

A composting toilet consists of a pedestal above a chamber or chambers designed to hold human waste for decomposition via an aerobic process controlled by the presence of bacteria, fungi and invertebrates (Dickson, 2000). Such waterless systems provide on-site treatment of human waste by reducing volume by up to 80-90 per cent and producing an end product called humus suitable for use as fertilizer (Molland, 1982). Appropriately designed composting toilets isolate human waste from the surrounding environment and are the preferred system for many high-use applications in sensitive ecosystems. As a result of this they can be installed without consideration of soil types (Crennan, 1992).

The main problems associated with the use of composting toilets at remote locations in Tasmania are twofold: a lack of microbial breakdown of solids and a lack of evaporation causing build up of liquid effluent leading to overflow and contamination of the surrounding environment. Both afflictions relate to the cool climatic conditions in which these toilets are required to operate. Crennan conducted a study of 24 composting toilets in Tasmania in 1992 and concluded that 16 were not composting at all and the remainder were only partially doing so (Crennan, 1992). In cool climates where composting toilets show a lack of composting activity liquid runoff is inevitable (Holman and Todd, 2001).

2.3 PROBLEM: LIQUID RUNOFF FROM COMPOSTING TOILETS

A build up of liquid effluent and the associated runoff problem occurs when climatic conditions do not allow the liquid contained in the holding tank or evaporation tray (where relevant) of a composting toilet to evaporate adequately. In these circumstances contamination of the local environment ensues. This is a major problem because liquid toilet effluent contains pathogens along with high levels of nutrients (Brassington, 1999). This presents a serious risk to humans, animals and plants upon entry to an environment such as a campsite where drinking water is collected, animals are present and the local vegetation is adapted to the low nutrient soils typical of highland Tasmania.

2.3.1 PATHOGENS PRESENT IN LIQUID HUMAN EFFLUENT

Pathogenic organisms present in liquid human effluent include bacteria, viruses, protozoa and helminths. These are all subject to transmission via water (Crennan, 1992; Brassington, 1999).

Bacteria are adept at surviving for long periods in cool moist conditions such as those encountered in damp soil, examples such as *Salmonella* have been shown to survive for two years in similar conditions (Awad, Ross and Lawrie, 1989). Other bacteria present in liquid human effluent include *Escherichia coli, Campylobacter fetus-jejuni, Yersinia enterocoliticia, Shigella dysenteriae, Vibrio cholerae* and *Leptospira* spp. (Fordham, 1990). Oral ingestion of such bacteria can cause serious illness to animals and humans and the ability of some bacteria such as *Salmonella* to survive outside a host is central to effective faecal management strategies at remote campsites.

Viruses reproduce and grow specifically within their animal or human host (Crennan, 1992). Enteric, or intestinal, viruses can contaminate water, enter the human body and multiply in the intestine causing illness and then re-contaminate drinking waters when excreted in large amounts from the body causing a cycle of disease. Around 140 types of these viruses can contaminate water and therefore provide a major threat to human and animal health in a wilderness situation. Examples of these diseases include Poliovirus, Coxsakievirus, Echovirus, Astrovirus and Adenovirus (Crennan, 1992; Bitton 1994). According to Gerba et al. (1975) human enteric viruses can survive for extended periods in the environment, thus presenting a major health risk when present in ground or surface waters.

Protozoa are parasitic zoonoses that use animals or humans as hosts to reproduce and are spread where cysts containing the protozoa are shed in faeces. Parasitic zoonoses are easily transferable from animals to humans. In remote camping areas the presence of such diseases can result in a cycle of infection. *Giardia* and

Cryptospiridium are most common in wilderness areas (Brassington, 1999). These protozoa represent serious health risks to both humans and animals. Measures to counter the transfer of viruses and protozoa must consider transmission between animals and humans and accordingly, isolate animals from faecal pathogens both inside and outside remote composting toilet facilities.

Helminths are parasitic worms that live in the intestinal tract of their hosts. They are transmitted through the excretion of eggs that become infective after either developing in soil or spending sufficient time in the intestinal tract. These include Hookworm, Roundworm, Threadworm and Beef/Pork Tapeworm (Crennan, 1992; Berry, 2000). The risk to human health presented by the presence of helminths at campsites is possibly not as significant as that provided by the other pathogens described above due to severe infections usually only being associated with extremely undernourished or unhealthy children (Berry, 2000).

2.3.2 NUTRIENTS PRESENT IN LIQUID HUMAN EFFLUENT

Table 2.1 indicates the average daily production and nutrient content of human urine and faeces. The amount of effluent produced per person per day changes significantly depending on ethnic background, age, diet, health, gender, fluid intake and climate of the individual concerned (Berry, 2000).

	Urine (L)	**Faeces (wet weight/grams)**
Per Person	1.2	150
Nitrogen (g/ppd)*	11	2
Phosporous (g/ppd)	1	0.6
Potassium (g/ppd)	2.5	0.6

Table 2.1 Average daily production and nutrient content of human urine and faeces (Del Porto and Steinfeld, 1999)

***(Grams/person per day)**

2.4 EXISTING SOLUTIONS

Where composting toilets are installed, the Tasmanian NPWS have designed solar evaporators for the abatement of the liquid effluent runoff problem present at campsites that are located in ecologically sensitive areas subject to low mean temperatures. However, the existing design results in considerable visual intrusion on the natural landscape through sheer size (in the order of $10m^2$) caused by relying heavily on direct sunlight to operate in conditions where few clear days are experienced. Also, these evaporators are not closely matched to the effluent output loads of the composting toilets to which they are attached.

Rota-Loo manufacture an evaporator consisting of a Soltran TM Module and Excess Liquid Tank. This design uses a fan to draw air over the body of liquid effluent and across a stainless steel sheet that is preheated using solar insolation. In conditions of low liquid effluent volume and regular direct sunlight this design approach would be appropriate. However, the reliance on heat from direct sunlight is inappropriate for use in Tasmanian Alpine conditions (Burrows, 2000).

Urine separation technology is used primarily to provide pathogen free fertilizer (the urine) for growing crops and household plants (Jonsson et. al., 2002). The use of urine diversion at remote campsite toilets in Tasmania would reduce the likelihood of transmission of faecal bound pathogens by removing the excess liquid before contamination with faeces. However, the disposal to the ground of the urine would still present a major problem for low nutrient adapted native flora because most of the nutrients excreted from the human body are contained in the urine (Table 2.1). If the diverted urine was removed using appropriate evaporation technology a situation where the majority of the effluent transferred for evaporation was free of faecal pathogens might be achieved. Unfortunately, as diverted urine would not have travelled through the compost pile where exposure to temperature conditions conducive to evaporation would occur, the volume of liquid to be evaporated may prove to be greater than in a non-diversion approach. Human contact with faecal pathogens during maintenance would be less likely as the diverted urine in the evaporator would have limited exposure to faecal pathogens. The diversion of urine is not explored in this thesis but may warrant further examination for application to toilet infrastructure in remote cool temperate climates.

Absorption trenches are commonly used for septic outflow treatment in on site human effluent disposal systems. An absorption trench is excavated into the ground along the natural contours of land and contains a slotted pipe, gravel and porous geo-textile cloth. These trenches are usually used in conjunction with septic tank systems and constitute 81 per cent of on site systems in New South Wales, Australia (Schwizer and Davidson, 2001). Absorption trenches are permeable to water and thus provide no barrier to prevent the effluent contained therein entering the soil and groundwater surrounding the trench. Such an arrangement is not suited to the disposal of human liquid effluent in areas where water and soil contamination are to be avoided and thus are not a real alternative to the evaporation approach explored in this thesis.

2.5 VISUAL INTRUSION OF TOILET INFRASTRUCTURE ON THE NATURAL LANDSCAPE

> *In this age of environmental awareness, pressure is mounting for the development of tourist facilities in wild and remote places. Wilderness areas, World Heritage areas and National Parks are obvious targets for their recognised environmental and scenic value. However insensitive development, and in some circumstances any development at all has the potential to destroy those values.* (Drew, 1989, p.6)

These comments were made within the context of an introduction to the proceedings from "Architecture in the Wild", a Royal Australian Institute of Architect's Professional Development Program conference held at Cradle Mountain in Tasmania.

Human visitation to Tasmania's wild places has reached a point where toilet facilities must be provided inside National Parks and World Heritage areas. Although these facilities have a visual impact on the landscape aesthetic pollution must be balanced with the notion that a lack of toilet facilities would create a greater impact on the environment than the visual component necessary to provide a functional composting facility. Drew, in the above quote, implies that this requirement for infrastructure has the potential to destroy or erode the very values that visitors are coming to experience. As a result, the impact of toilet infrastructure on the vernacular aesthetic must be an inherent consideration in the design process for technology applied to this environment.

Therefore, the size of a liquid human effluent evaporator must be minimised to reduce visual impact on the local environment. Although the evaporator is a necessity it is very important to make it as small as possible. Also relevant is the way in which toilet technology is placed in a sensitive environment. The greater the flexibility in sighting offered by evaporators the better the opportunity to place them in shaded or secluded areas to reduce visual pollution. Performance in diffuse light and shaded conditions has been deemed paramount to this aspect of the reduction of visual impact.

2.6 OTHER RELEVANT DESIGN FACTORS

Though the efficiency and visual intrusion of the evaporator are considered extremely important there are other factors that must be considered that relate to the incentive for adopting this design.

In order to provide a financial incentive for uptake of this new evaporator design it was deemed necessary to create it at a cost close to or less than that incurred for the evaporator designs currently employed by the Tasmanian NPWS. The cost associated with the implementation of these is in the order of $2-4000 per unit once installed.

Oliver Vaughan (pers. comm. 2003) of the Tasmanian NPWS has indicated that Rangers generally want little or no part in maintaining toilet facilities. With this consideration in mind the evaporator designs in this thesis will all be aimed at requiring the absolute minimum in terms of maintenance input.

2.7 EVAPORATION THEORY

An examination of the theory of evaporation is presented to introduce the main scientific basis for this work. The emphasis is twofold: the extent to which evaporation will "purify" water; and the process by which it occurs.

2.7.1 THE PROPERTIES OF WATER

Water is unique in that it has a high heat capacity requiring comparatively large amounts of energy to cause a rise in temperature. Similarly, removal of energy results in a comparatively small reduction of temperature than that encountered with other substances. This direct relationship between energy input and temperature change is referred to as sensible heat.

Water is present in all physical states at temperatures encountered in normal atmospheric conditions namely solid (ice), liquid (water), and gas (water vapour). These various phases are achieved through the release of energy in the instance of changing from water vapour to water (condensation) or from water to ice (freezing) or the addition of energy in the case of changing from solid to liquid (melting) or liquid to water vapour (evaporation).

Evaporation occurs when water molecules of the highest kinetic energy escape the surface of water and leave behind those with less kinetic energy. Many more molecules escape the surface of water than are taken away in measurable evaporation. This is the case because though kinetic theory suggests that 10^{22} molecules escape from 1 cm^2 of water per second, most do not have the energy or momentum to resist returning to the water body. If they did the water would evaporate in approximately 3 seconds and the loss of heat associated with the most energy-laden molecules would rapidly cause the water to freeze, slowing the evaporative process significantly (Bauman, 1966).

This escape of molecules from the surface of a body of water requires a change in phase from liquid to gas involving the storage of what is termed latent heat in molecular bonds, a process that requires significant amounts of energy. This type of heat is characterised by an increased energy input resulting in a change of phase rather than temperature. To provide an example of the capacity of latent heat storage in water, the evaporation of one litre of water necessitates an energy input equivalent to heating six litres of water from 0 to 100°C (Oke, 1978). The amount of energy required to evaporate water is called the latent heat of vaporisation; its value is 2480 kilojoules per kilogram at 10°C (Oke, 1978). This energy is contained in the water vapour until condensation occurs. The uptake and removal of energy from a water body due to evaporation is called evaporative or adiabatic cooling. As illustrated above, adiabatic cooling retards evaporation because the greater the evaporation rate, the faster the energy contained in the system is removed from the water body and surrounding air as heat.

Relative humidity has a significant effect on evaporation in that the evaporation rate increases if the vapour pressure at the water surface is greater than that of the surrounding air. The lower the relative humidity, the greater the gradient between the vapor pressures at these two points and accordingly, the greater the rate of evaporation (Critchfield, 1983).

The factors affecting the rate of evaporation of water from a container are the input of energy, water surface area, air movement and the relative humidity gradient. This thesis examines the means by which evaporation occurs, especially in cool and overcast circumstances and exploits them in the relatively controlled environment of an evaporator.

2.7.2 WATER PURIFICATION THROUGH EVAPORATION

Distillation of effluent from a water treatment plant was shown to bacteriologically purify and separate water from suspended and dissolved solids by Singley (1971). To some degree, the process of distillation can be used as a gauge for the extent to which the water evaporated from a body of blackwater has been purified. The process of distillation results in the removal of dissolved and suspended solids to the point where only a few milligrams per litre remain (American Society for Testing a Materials, 1969, p.44). However, conditions present inside a solar evaporator differ to those encountered in a still, in that a large throughput of air is used to aid evaporation. The ramifications are examined below.

2.7.3 TRANSPORT OF MICROORGANISMS THROUGH THE AIR

Particularly relevant is the potential for transport of pathogens present in a composting toilet evaporator to the surrounding environment. If significant numbers of viable pathogens are transferred to the environment through the air, humans and animals in the vicinity can be exposed to infection risks similar to those present when pathogens enter surface or groundwater. Accordingly, the potential for distribution and subsequent infection via solar evaporation must be evaluated. Of particular interest are the processes that aid the removal of some pathogenic organisms from blackwater, the extent of distribution and the viability of any pathogens that escape.

2.7.4 BIOAEROSOL FORMATION

The dispersion of pathogens through the air takes place in the form of bioaerosols. A bioaerosol is a collection of airborne particles of a biological nature (Stetzenbach, 2002). As a general rule bioaerosols are formulated as polydispersed particles or droplets of 0.5 to 30 μm diameter (Lighthart, 1994). In the case of water borne organisms, bioaerosols are formed predominantly through wave and splash action or bursting bubbles wresting the particles from a body of water and into the air. Airborne particles often consist of a conglomerate of organisms including bacteria, fungi and viruses surrounded by a thin layer of moisture (Stetzenbach, 2002).

In a 2004 study, Reinthaler et al. examined the presence of airborne microorganisms in the vicinity of biological waste composting plants. They found that significant levels of airborne microorganisms are present during the process of pile turning at organic waste composting facilities. Regular wetting of the compost piles before disturbance achieved a reduction in the emission of bioaerosols from the plant to the extent that initial detection distances of 800m from the facility were reduced to 500m. This would suggest that more bioaerosols are emitted from a drying compost pile than from any liquid effluent running from it, especially during disturbance operations such as turning.

2.7.5 BIOAEROSOL DISTRIBUTION

Once airborne, the extent to which bacteria, viruses and fungi contained in a bioaerosol formation derived from blackwater waste are distributed is relevant to the risk assessment of a solar evaporator. Bioaerosols have been observed to travel large distances in studies such as those conducted by Bovallius et al. (1978) which found that red sand and bacterial spores of the *Bacillus* genus were swept into the air in a dust storm in Turkey and transported to Sweden over a period of two days. In terms of vertical transport Imshenetsky et al. (1978) observed bacteria and fungal spores to achieve a vertical lift of 77km. Although these examples suggest that transport of bioaerosols is possible over large distances much evidence is available to suggest that the majority of airborne microorganisms survive for a short period of time once aerosolised (Stetzenbach and Lighthart, 1994).

2.7.6 BIOAEROSOL VIABILITY

Mohr, in a 2002 study, found that relative humidity, temperature and oxygen were the three most significant factors influencing the viability of airborne microorganisms (Mohr, 2002, p. 827). Mohr further deduced that air ions, solar irradiation and open-air factors (OAFs) influence the viability of these particles to a lesser degree. Most microorganisms present in the form of bioaerosols are immediately inactivated on aerosolosation as a result of dessication, temperature change and concentration factors. Those that survive the aerosolisation process are subject to environmental factors of which relative humidity is the most likely to render them unviable.

Conditions of low relative humidity cause a reduction within a bioaerosol of the water that is vital for normal exterior function of many microorganisms thus killing or inactivating them. When subjected to low relative humidity situations the cell membranes of many organisms such as *E.Coli* B experience conformational changes from crystalline to gel phases causing cell protein damage and subsequent loss of viability. Moreover, a situation of changing relative humidity is more likely to render microorganisms in a bioaerosol inactive through loss of aerosol stability than conditions of more constant relative humidity (Mohr, 2002).

Most fungal spores become unviable when exposed to open-air factors with the notable exeption of *Penicillium expansum*, which appears to be exceptionally robust (Griffiths et al. 1999). This genus of fungal spore is associated with allergic reactions and toxicosis but is more likely to be a major problem for human health upon long-term exposure in indoor environments (Lighthart and Mohr, 1994). Fungal spores are well adapted to situations of high temperature, low humidity and high solar insolation that kill most bacteria but fungal sporation is inhibited in wetter conditions that are more conducive to bacterial growth. Bacterial growth is, however, inhibited in cold conditions. Most fungal spores present in the atmosphere are dead or cannot be cultured and therefore considered unviable (Lighthart and Stetzenbach, 1994).

Wastewater evaporators are unlikely to provide circumstances that enable large amounts of bacterial, viral, and fungal particles to be removed from the liquid effluent contained inside. However, it is likely that some bioaerosols are emitted. The potential for transport of these bioaerosols is dictated by weather and would be significant in the presence of favourable meteorological conditions. However, the viability of bioaerosols in the environment is very low and disease transmission pathways are relatively small compared to the direct escape of liquid toilet effluent into surface and groundwater or from bioaerosols emitted directly from drying compost piles.

CHAPTER 3

Methodology and Design

3.1 INTRODUCTION

The design of an efficient evaporator for removing liquid toilet effluent in cool conditions requires a quantitative understanding of the extent to which various design factors influence performance. This chapter outlines the series of preliminary design and testing methodologies that were used to test and incorporate improvements into a final design used for field testing. The various testing methods employed for laboratory experiments, outdoor testing on-site at the University of Tasmania and field-testing at Lake Dobson, Mt Field National Park are described. Results are presented for preliminary laboratory and outdoor control testing; those relating to prototype and field testing are contained in the results chapter (chapter 4).

Testing was conducted in four phases in order to gradually work toward the goal of designing and constructing an efficient evaporator. The first phase of testing in the laboratory provided experiential familiarity with the workings of evaporation and indicated general areas in which to concentrate in order to provide increased efficiency. The second phase of testing looked at various means by which to apply the experiential knowledge gained in the laboratory through design of a prototype evaporator. The third phase of design and testing fine-tuned the accumulated knowledge and experience from the previous testing into a field ready design and the fourth and final phase involved a real-world application of the field test evaporator. The first three phases were conducted using water as the medium for evaporative testing due to the health risks associated with handling liquid toilet effluent. Phases one through three were carried out under the assumption that factors providing an improvement in the evaporation of water would elicit a comparable response with liquid toilet effluent. Phase four was undertaken using the effluent from the composting toilet facility located at Lake Dobson Government Huts in the Mt Field National Park.

3.2 TESTING PHASE ONE: LABORATORY TESTING

In order to gain experience with the factors that influence the evaporation of water from shallow containers with large surface areas, a series of experiments was undertaken using the controlled conditions of the laboratory.

3.2.1 TESTING METHODS

Two identical shallow clear plastic vessels were used for evaluating basic evaporation principles. These had a surface area of .084m^2 when the 280 by 300mm vessels were filled with either 500 or 1000mL of water. Once filled, the vessels were weighed on an electronic scale with 5g resolution and placed on the laboratory bench. A whirling hygrometer was used to measure wet and dry bulb ambient air temperatures and a conversion slide was employed to convert these daily readings for determining the relative humidity of the air. A series of tests were undertaken to determine the effects of air movement and water surface area.

3.2.2 LABORATORY TEST RESULTS

The first basic evaporative test involved filling each of the vessels with 500mL of water to evaluate the effectiveness of a side-by-side testing model in providing a control measure (Table 3.1).

Table 3.1 Results from initial laboratory evaporation experiment

	Weight (kg)			
	Tray B	**Tray C**		
Initial weight of tray	.320	.315		
Initial weight (tray + water)	.810	.810		
Date			**Temp (°C)**	**R/H(%)***
22/01/01 12.40 pm	.810	.810	25	52
23/01/01 11.20 am	.740	.740	24.5	49
24/01/01 11.45 am	.665	.665	23	52
25/01/01 1.15 pm	.590	.590	23	60
26/01/01 12.30 pm	.520	.520	22	60
Total evaporation	.290	.290		

* R/H% = Relative Humidity expressed as a percentage.

Within the reading accuracy of the scale the experiment indicated that the evaporation from the two vessels was identical. The R^2 value of 1 indicated a perfect Pearson product moment correlation confirming that one vessel could be used as a control to determine the effect on evaporation of modifications to the other, or to the environment in which the other operated.

3.2.2.1 Surface area

A simple test was performed to evaluate the impact of surface area on evaporation using one vessel as a control (Tray C) while varying the other with the addition of a single cotton rope wick of 10mm diameter draped from a height of 15cm into the water (Tray B). It was hypothesised that the addition of a wick would increase the evaporation rate due to the wicking effect drawing the water beyond the surface and increasing overall surface area (Table 3.2).

Table 3.2 Results from surface area laboratory experiment

(Tray B includes cotton rope wick, Tray C control)

		Weight (kg)		**Weight loss (kg)**			
		Tray B	**Tray C**				
Initial weight of tray		.615	.320				
Initial weight with water		1.6	1.295	**Tray B**	**Tray C**		
Date	**Time**					**Temp (°C)**	**R/H%***
23/03/01	4.00pm	1.6	1.295	N/A	N/A	22	78
24/03/01	12.45pm	1.55	1.25	.05	.045	22	71
25/03/01	5.50pm	1.45	1.19	.1	.06	21.5	71
26/03/01	12.00noon	1.275	1.13	.175	.06	21.5	60
27/03/01	8.10pm	1.125	1.03	.15	.1	18.5	50
28/03/01	12.40pm	1.06	.98	.065	.05	19	58
29/03/01	4.35pm	.96	.915	.1	.065	19	62
30/03/01	10.30am	.905	.875	.055	.04	19	62
Total Evaporation				**.695**	**.420**		

*R/H% = Relative Humidity expressed as a percentage.

The enlarged surface area resulted in an increase in evaporation of .275 kilograms over the testing period representing a 65% improvement in evaporation compared to the control. A t-test conducted on the weight loss data from Table 3.2 proved the addition of the cotton rope was significant within a 95% confidence interval. This supports the hypothesis presented that the use of the wick system would increase evaporation.

In order to compare the effectiveness of potential wick substances several absorbent materials were selected: nappy material, cotton rope, pure cotton towelling material and a pure cotton weave. Each of these was draped over a frame and into one of four identical containers holding the same amount of water. Observations were made over a period of several weeks to determine the material that performed best as a wick. This simply involved observing the residual water inside each container to compare the rate of evaporation. These observations indicated that the use of pure cotton towelling material in the laboratory provided the greatest improvement in evaporation by approximately 40% of the residual volume.

Further testing was undertaken prior to the construction of the field test evaporator regarding the efficiency of different colours of pure cotton towelling material when exposed to sunlight. The above method was followed using one black and one white wick presented in containers placed in direct sunlight. This indicated an advantage to using black material of approximately 30% of the residual volume; this was subsequently incorporated into the field test evaporator design.

3.2.2.2 Air movement

Air movement was studied by placing an electric fan in such a position as to allow the air to be directed over the surface of the water in one vessel (Tray B) and to exclude this process from the other. This allowed Tray C to act as a control. The test was conducted without a wick and a hot wire anemometer was used to measure air velocity just above the surface of the water (Table 3.3).

Table 3.3 Results from air movement laboratory experiment

(Tray B exposed to air movement, Tray C control)

	Weight (kg) Tray B	Weight (kg) Tray C	Weight loss (kg) Tray B	Weight loss (kg) Tray C	Temp(°C)	R/H%	Wind Speed (m/s)
Initial weight of tray	.320	.315					
Initial weight with water	1.310	1.295					
Date							
21/02/01 2.20 pm	1.310	1.295	N/A	N/A	24	51	1.44
22/02/01 2.20 pm	.760	1.185	.55	.11	22.5	50	1.41
23/02/01 10.10 am	.390	1.125	.37	.06	22.5	60	1.41
23/02/01 1.15 pm	.345	1.115	.045	.01	22.5	67	1.34
Total Evaporation			**.965**	**.180**			

* R/H% = Relative Humidity expressed as a percentage.

The Table shows that 0.965 kg of water was evaporated from Tray B over the period of the experiment compared to a figure of 0.180 kg for Tray C indicating that increased air movement caused a 436% improvement in the rate of evaporation.

3.3 TESTING PHASE TWO: OUTDOOR CONTROL AND PROTOTYPE TESTING AT THE UNIVERSITY

3.3.1 CONTROL DESIGN

When experimenting in the outdoor environment, factors such as temperature, wind velocity and humidity varying with weather conditions, and the rate of evaporation vary from day to day and therefore cannot be compared directly. In order to make working comparisons over different days, the relative performance between an unchanging control design and any modified design configuration was compared. This allowed quantitative assessment of the effectiveness of any changes made between testing periods via the use of a ratio (e.g. Performance of Prototype: Performance of Control).

A simple control evaporator designed to simulate the current type used by the Tasmanian NPWS for some composting toilets was constructed for this purpose. This consisted of an identical water containment vessel to that of the prototype, with a "Laserlite" and timber sloped cover (Plate 3.1). The lower edge was designed so as to have an air inlet area of $1400mm^2$ between the edge of the water containment vessel and the cover; the upper edge had an air outlet area of $1700mm^2$. The design relied on a process of heating the air inside the evaporator using solar radiation to create a thermosiphon effect due to the temperature difference between this air and the outside ambient air temperature. No wick was employed in this design and the water surface area was $0.18m^2$.

Plate 3.1 The control evaporator (450x480x690mm)

3.3.2 MEASUREMENT OF EVAPORATION

The variable measured during testing was the amount of water evaporated over a period of approximately 24 hours. A galvanised steel pointer was attached to the side of each containment vessel; when this just made contact with the water the unit was considered to be full. The evaporation rates were determined by measuring the amount of water added to each containment vessel at the end of each test period until the surface of the water came into contact with the pointer. This method was bench tested using a process of setting the unit to full, removing enough water to break contact with the pointer and refilling until contact between the pointer and the surface of the water was re-established. This bench testing approach indicated an average error of +0.7mL per reading (See Appendix D).

3.3.3 CONTROL PLUS FAN DESIGN AND TESTING

A second control was constructed using the same design as the first for the purpose of testing the change in evaporation facilitated by the use of a solar powered ventilator unit that was intended to create air movement through the prototype evaporator.

The two controls were compared prior to the attachment of the solar ventilator to establish the similarity in the performance of the two (Table 3.4).

Table 3.4 Results from control comparison test

Date	Time	Temp(°C)	R/H%*	Evaporation (Ml) Control 1	Control 2
16/02/02	4.20pm	25	30	full	full
17/02/02	5.55pm	21.25	59	655	625
19/02/02	5.15pm	21.25	57	725	775
20/02/02	3.30pm	23	71	385	500
21/02/02	4.50pm	18	42	350	325
22/02/02	7.45pm	19.5	62	340	270
24/02/02	6.00pm	21.5	67	865	760
Total evaporation				**3320**	**3255**
Performance ratio			**Control 1: Control 2 = 1.02:1**		

*RH% = Relative Humidity expressed as a percentage.

The control ratio calculated with the data in table 3.4 indicated that the two are similar in their performance. Control 2 achieved a slightly higher total evaporation level. Figure 3.1 provides a graphical comparison of the similarity of the two evaporators.

The departures of the data from the 1:1 line in Figure 3.1 could have been caused by small differences in the degree to which sunlight or wind was contacting each of the control evaporators as a result of their orientation. Also, despite being very similar in design and construction the controls were not absolutely identical. The R^2 figure of 0.86 does, however, indicate a very good fit.

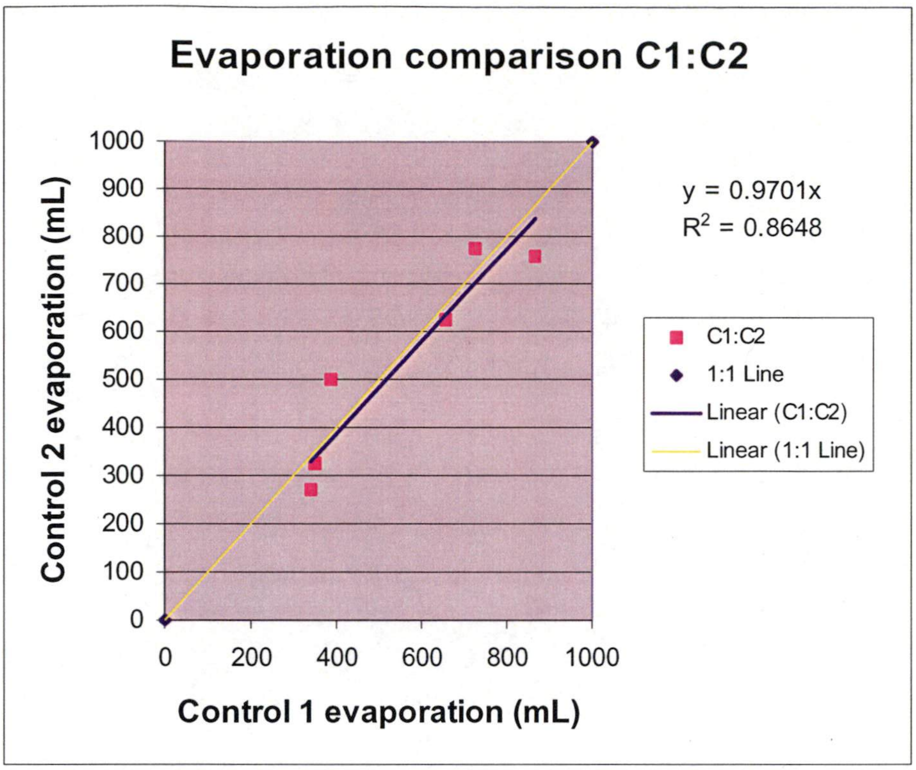

Figure 3.1 Comparison of control evaporators

Following the comparison above, the solar powered fan ventilation unit was added to the second control in order to determine the effect of this device on evaporation performance. This was accomplished by adding a plywood and radiata pine chute at the rear of the evaporator to which the ventilation unit was attached (Plate 3.2). The results from this test are presented in Table 3.5.

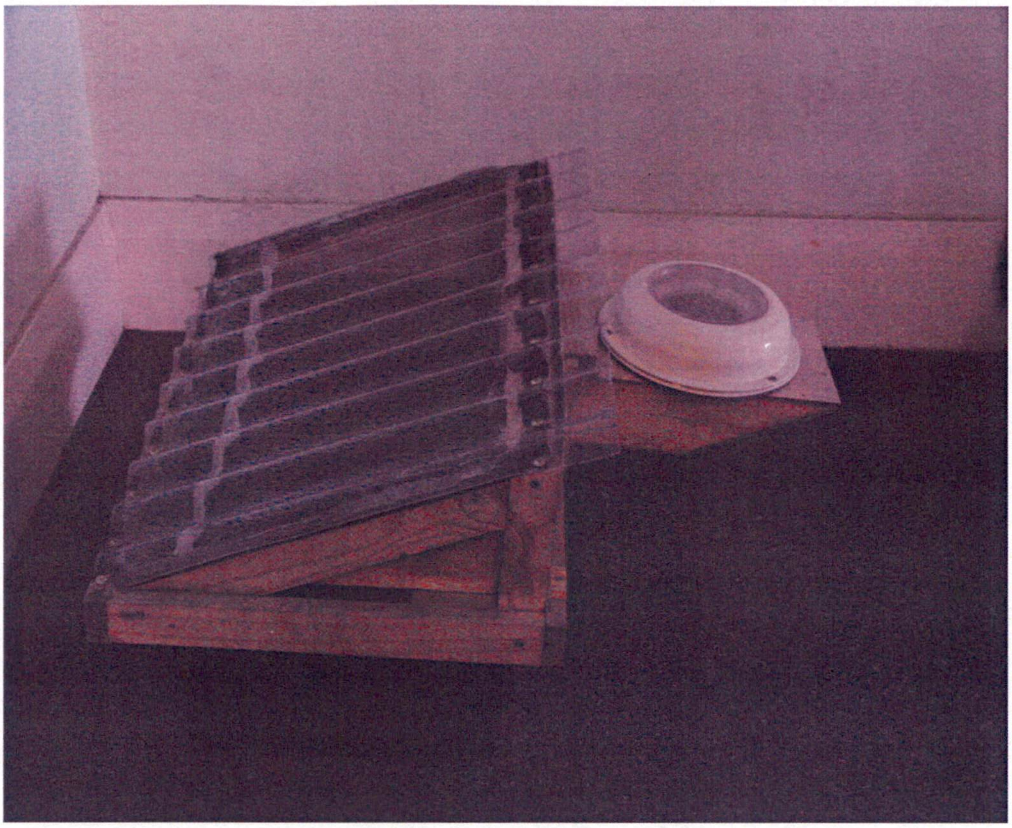

Plate 3.2 The control evaporator 2 plus ventilator

Table 3.5 Results from control 2 plus ventilation unit test

				Evaporation (mL)	
Date	**Time**	**Temp(°C)**	**R/H%***	**Control 1**	**Control 2**
05/03/02	5.07pm	24.5	51	full	full
06/03/02	5.17pm	21.25	69	240	465
07/03/02	5.00pm	19	51	325	370
08/03/02	6.00pm	17.5	64	275	310
09/03/02	6.25pm	18.5	65	315	430
10/03/02	8.10pm	17.5	73	525	500
11/03/02	6.05pm	26	35	585	510
12/03/02	5.04pm	19.5	44	275	390
13/03/02	6.30pm	19.5	51	375	330
14/03/02	7.00pm	19.5	47	400	570
15/03/02	7.40pm	19.25	60	375	340
16/03/02	6.10pm	18.5	78	150	150
17/03/02	6.35pm	20	57	425	470
18/03/02	7.10pm	22	49	550	570
19/03/02	7.40pm	19	51	470	500
20/03/02	7.10pm	15	63	0	210
Total Evaporation				**5285**	**5905**
Performance Ratio			**Control 1: Control 2 = 1:1.117**		

*R/H% = Relative Humidity expressed as a percentage.

This test indicated an increase in the performance of Control 2 over the previous side-by-side control test demonstrating that the solar powered ventilation unit improved evaporative performance. Figure 3.2 provides a graphical representation of the control 2 plus ventilation unit versus control 1 test.

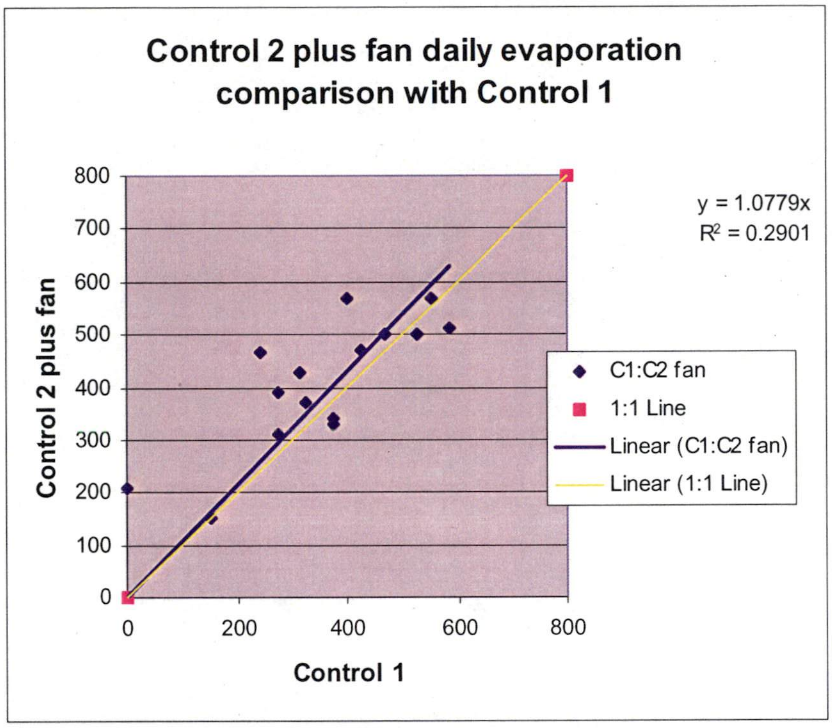

Figure 3.2 Ventilation unit evaluation

The fact that most of the points appear above the 1:1 line reinforces the notion that the addition of the fan has increased evaporative performance. Those points at or below the line suggest that certain conditions favoured control 1. This could be attributable to extra heat retained from slower movement of air through the control unit and the same wind and sun shading effects suggested in the evaluation of the control comparison in Figure 3.1. The superior performance of the fan-assisted control for most conditions indicates the effectiveness of air movement in aiding evaporation.

3.4 PROTOTYPE EVAPORATOR DESIGN

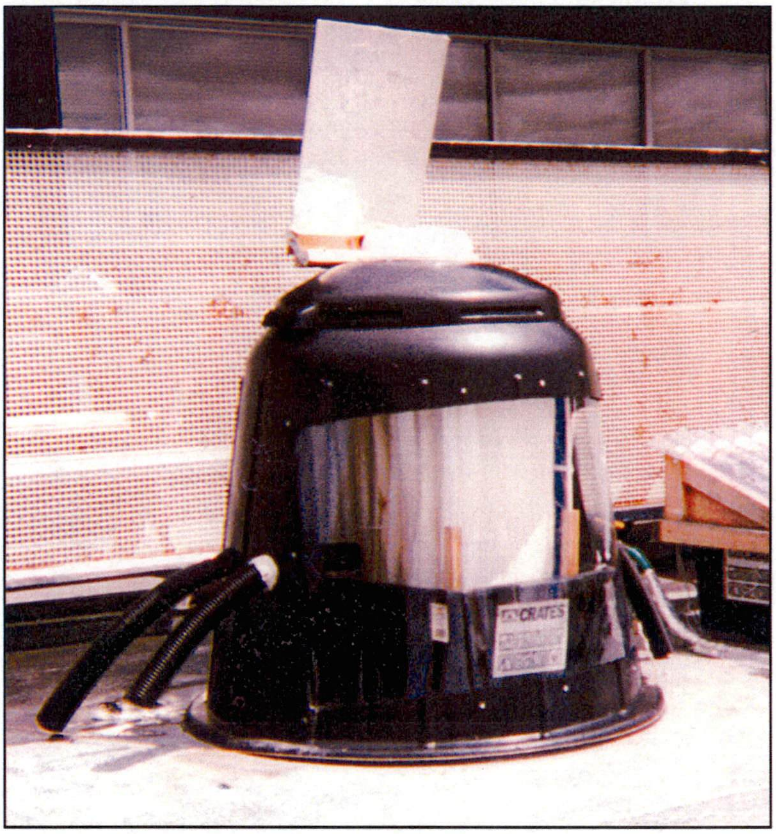

Plate 3.3. The prototype (version 5)

The prototype evaporator design (Plate 3.3) sought to bring together the factors identified in laboratory testing as important to increasing evaporation efficiency namely, air movement and increased water surface area with the provision for heat uptake. The features associated with each property were examined in a series of versions.

3.4.1 ENCLOSURE

An enclosure was deemed integral to the design of the evaporation unit to assist the containment of heat gained from solar radiation and exclude rain, insects and animals from the device. It was necessary to exclude animals and insects as they can act as transport vectors for pathogens contained in toilet effluent. The enclosure also helped to control the direction of air across the water and wick surfaces. A black polyethylene compost bin with a base diameter of .7m and a height of .8m was chosen for this application.

3.4.2 AIR MOVEMENT

The final version of the prototype created air movement via a solar powered ventilator making use of a reflector and directed the air using black plastic inlet tubes. The process involved movement of air from outside the evaporator, through the inlet tubes, across the surface of the wick (described below) and out through the uppermost point of the evaporator.

The solar powered "Sunvent" ventilator was obtained for $90 and consisted of two half-circle photovoltaic cells and a fan in a self contained waterproof unit capable of extracting up to 19 cubic metres of air per hour in bright sunlight (based on accompanying information included with product). The ventilator employed no energy storage medium, a design property facilitating low maintenance. In order to increase the amount of solar radiation hitting the surface of the photovoltaic cells the use of a 0.1 square metre reflector made of plywood backing coated with aluminium foil was examined. This was placed at an angle of approximately 70 degrees to the horizontal to achieve the greatest fan speed on overcast days. In order to decide the appropriate angle for the reflector, it was moved until the fan was observed spinning at its fastest on an overcast day.

The three plastic ventilation tubes, used from version 1.1 to 6.0, had a combined inlet area of $1200mm^2$ with the black surface being selected to aid passive solar heat uptake and to transfer this heat to the air entering the evaporation unit to enhance its moisture holding capabilities. These inlets were directed in such a way as to move air from the outside of the evaporator and through the wick, prior to removal via the ventilation unit outlet. Without this direction the air might bypass the wick and water surfaces and proceed through the unit without making optimum contact with the wet surfaces.

3.4.3 INCREASED SURFACE AREA

An increase in the surface area of water contacting the air was achieved through the use of a pure cotton wick system. This consisted of a multi-rung frame (top and bottom) with the wick material woven through it to create a zig-zag effect when viewed from the side (Plate 3.4).

Plate 3.4 The wick viewed from above (frame = 280x580x370mm)

The wick was tested in two forms: the original wick consisting of 2.42m^2 of material surface area (prototype version 4.0); and a modified version with an increase in material to 4m^2 of surface area (version 6.0). These figures take into account both sides of the flat surface area of the material. Determining the true evaporative surface area of this wick when in use is complicated by the many fibrous protrusions from the surface and the changing extent to which the wick material is moist.

The surface area of the water in the containment vessel without the wick was 0.18m^2 making the combined potential evaporative surface area of the water 2.6m^2 in the case of the small wick and 4.18m^2 in the case of the large version.

3.4.4 PASSIVE SOLAR HEAT UPTAKE

Passive solar heat uptake was incorporated into the final prototype design with the use of a 0.4 m^2 transparent north-facing window (450mm high and 890mm long) combined with black plastic construction materials. The prototype was originally tested with a completely black outer shell (versions 1.0, 1.1 and 2.0) and then modified with the addition of a window (version 3.0 on). The water containment vessel was a black plastic "recycling bin" (235mm high, 560 by 345 mm top and 530 by 315mm base) selected for its effectiveness in aiding passive solar heat uptake to the water by absorbing solar radiation and transferring it on to the water contained therein. When in use, the containment vessel and controls were raised 20mm above the ground to reduce conductive heat loss/gain to/from the surface on which they were resting.

3.5 PROTOTYPE EVAPORATOR TESTING

Testing began with the prototype evaporator in a simple form. The water containment vessel was placed inside the windowless black plastic outer shell, the ventilation unit placed at the highest point, one inlet hose directed over the surface of the water and no wick. Once the performance of this basic design was determined via comparison with the control, changes were made at regular intervals to assess the effectiveness of increased air inlet area, increased passive solar input and increased evaporative surface area. The control evaporator remained unchanged throughout testing.

The same pointer based evaporation detection method was used for prototype testing as that described for the control. At the time of each reading air temperature was measured using a whirling hygrometer to determine wet and dry bulb readings for the determination of ambient air temperature and humidity. Data loggers were placed inside each of the evaporators to measure internal air and water temperatures logged at 10-minute intervals. These data were collected in order to assess the difference in performance between the control and prototype design in its various guises.

The results relating to the prototype- testing regime are presented in the next chapter and the various versions of the prototype are identified in Table 3.6.

Table 3.6 Key to the various prototype versions tested

Version	Description	Corresponding Prototype Evaporator Test
1.0	no window, one air inlet, solar ventilator, no wick	1.0
1.1	version 1.0 plus two more air inlet hoses	1.1
2.0	version 1.1 plus a reflector	2.0
3.0	version 2.0 plus a window	3.0
4.0	version 3.0 with no fan and a small wick	4.0
5.0	version 4.0 with a fan	5.0
6.0	version 5.0 with a larger wick	6.0

Prototype Evaporator Test 1.0 was conducted using version 1.0. This test was run over a three-day period. The reason for such a short testing period lay in the fact that no evaporation occurred for the prototype and insufficient inlet area was suspected as the cause. As a result of this the prototype version 1.1 used a further two inlet hoses and Prototype Evaporator Test 1.1 was then conducted over ten days.

At times, in overcast conditions it was noted that the fan had ceased to spin. Prototype Evaporator Test 2.0 was conducted to evaluate the effectiveness of the addition of a reflector for increasing the solar radiation hitting the photovoltaic cells that produce power to run the fan.

A window was added to evaluate the change in performance elicited from direct entry of passive solar radiation in Prototype Evaporator Test 3.0. Prior to this the passive solar heat uptake was transferred through convection, conduction and radiation from the black plastic exterior rather than as a direct result of the sun's rays hitting the internal components of the evaporator. It should be noted that the above addition of two inlet hoses would also have aided passive solar heat uptake due to the black colour and in the position of the sun.

Prototype Evaporator test 4.0 evaluated the performance of the prototype with a small wick and without the use of the fan to drive the movement of air. The failure of the fan device prompted a comparison with the configuration possible once a new fan was obtained for test 5.0. Prototype Evaporator Test 5.0 involved the addition of a new solar powered fan in order to determine the effect of an increase in the evaporative surface area of the unit over the configuration in test 3.0. Prototype Evaporator Test 6.0 tested the effect on evaporation of the increase in wick surface area from $2.42m^2$ to $4.0m^2$.

3.6 TESTING PHASE THREE: OUTDOOR FIELD TEST EVAPORATOR DESIGN AND TESTING AT THE UNIVERSITY

The field test evaporator design incorporated the knowledge gained from prototype evaporator testing with some new ideas resulting from the prototype testing experience.

3.6.1 THE ENCLOSURE

The enclosure design for the field test evaporator marked a departure from that employed in the prototype. The use of black plastic was eliminated and replaced with a completely clear outer shell. This decision related to the success of incorporating a window into the prototype and a desire to increase the level of diffuse light entering the unit.

The material used for the enclosure was "Laserlite – Twinwall"; a polycarbonate twin walled sheeting with heat insulating properties. This sheeting was 8mm thick and consisted of two skins joined by parallel ribs. The cells formed by these ribs prevented the formation of convection currents thus reducing the transfer of heat from one side of the sheet to the other. It was proposed that the use of such material would aid heat retention and thus evaporation.

The enclosure consisted of a $1.5m^2$ base four sided pyramid shape incorporating 60° equilateral triangles with the upper tip removed to allow for fitting of the solar powered ventilation unit (Plate 3.5). This shape was selected because it provided a reasonable space for the wick system and acted as a funnel to allow air to be directed through the unit.

The air inlet approach on the field test design also represented a significant departure from that used on the prototype. The tubes of the prototype were thought to be restricting airflow into the evaporator and preventing wind from assisting this movement of air. The final design used two rectangular air inlets measuring 950x40mm that allowed wind to assist the movement of air through the evaporator. These are combined with angled "Laserlite-Twinwall" guides to direct the air onto the surface of both the effluent contained in the unit and the wick. An aluminium gutter was placed above each inlet to prevent water entering the unit and a screen was secured over each inlet to prevent the entrance of insects. These air inlets are visible in Plate 3.5.

The enclosure was assembled using aluminium angle and flat bar secured with nuts and bolts. This approach was adopted to allow dismantling for transport.

Plate 3.5 The field test evaporator design

3.6.2 THE WICK

The wick system of the field test evaporator differed from that used in the prototype in two main elements of design. Firstly, black pure cotton-towelling material was adopted instead of the white used for the prototype as the darker material increased the uptake of heat from solar radiation. Secondly, the orientation of the zig-zag wick shape was changed from the prototype in such a way as to allow the air entering the unit to travel across the surface of the effluent contained in the tub and into each wick until it reached a point where the only option was to travel vertically up the wick surface and out through the solar powered ventilator at the top of the unit. This 90° change in orientation was adopted to create a smooth flow of air through the unit and to maximise air contact with the wick surface (Plate 3.6).

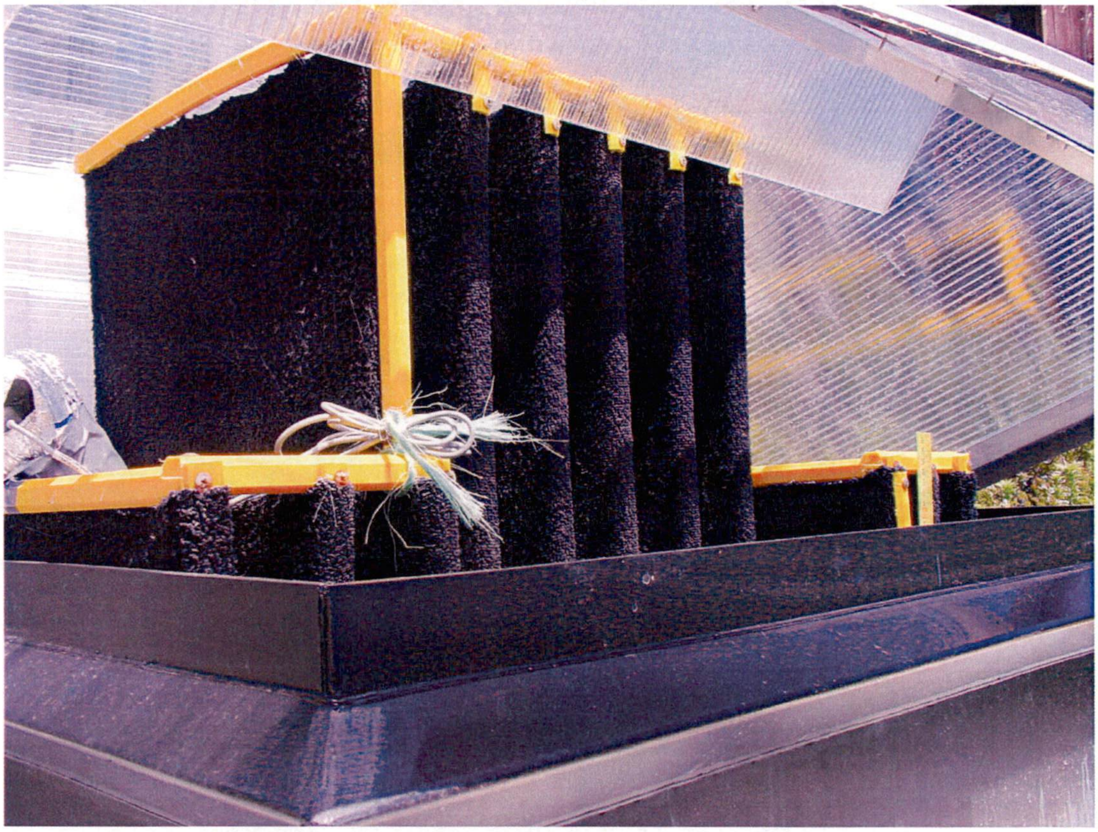

Plate 3.6 The field test evaporator wick

The system in the final design consisted of three separate wicks (Plate 3.6). This was incorporated into the design to allow simple assembly and to maximize the amount of wick surface area. The frame of these wicks was made from six sided plastic rod joined with self-tapping screws. The edges of the material were prevented from sagging by securing one end of a piece of fishing line to the frame, weaving it through each edge of the material with the use of a sewing needle and then tensioning the fishing line by securing it against another section of frame.

3.6.3 The Ventilation Unit

The same type of ventilation unit used in the prototype design was modified for use with the field test evaporator. A Ventilation Unit Modification Test was conducted to increase the airflow capacity. Two anemometers, two ventilation units and two identical cardboard tubes were used. The tubes were 100mm in internal diameter and 435mm in length and the anemometers were each LCA 6000 rotating vane models. Each tube had an anemometer attached to one end and a ventilation unit attached to the other. The ventilation units were identical apart from the outlet area. Spacers were placed on the modified unit to increase the outlet gap from between 5 and 25mm from the standard gap of 3mm. The ventilators were placed in direct sunshine to activate the photovoltaic cells while readings were taken to compare the wind speed at the end of each tube detected by the anemometers. The 25mm outlet gap resulted in a significant increase in the amount of air moved and was adopted accordingly. The results of this experiment are contained in Appendix C while a pictorial representation of the modified ventilator is shown below in Plate 3.7. A screen was also fitted to the ventilation unit to exclude insects.

As per the prototype, a reflector was used to increase the performance of the solar cells on the ventilator. This reflector was made from a single piece of polished aluminium plate and was secured on an angle of 70° to the horizontal.

The "Sunvent" ventilator was secured to a piece of flat aluminium plate and then attached to the flat top of the enclosure using plaster screws and a rubber seal as pictured in Plate 3.7.

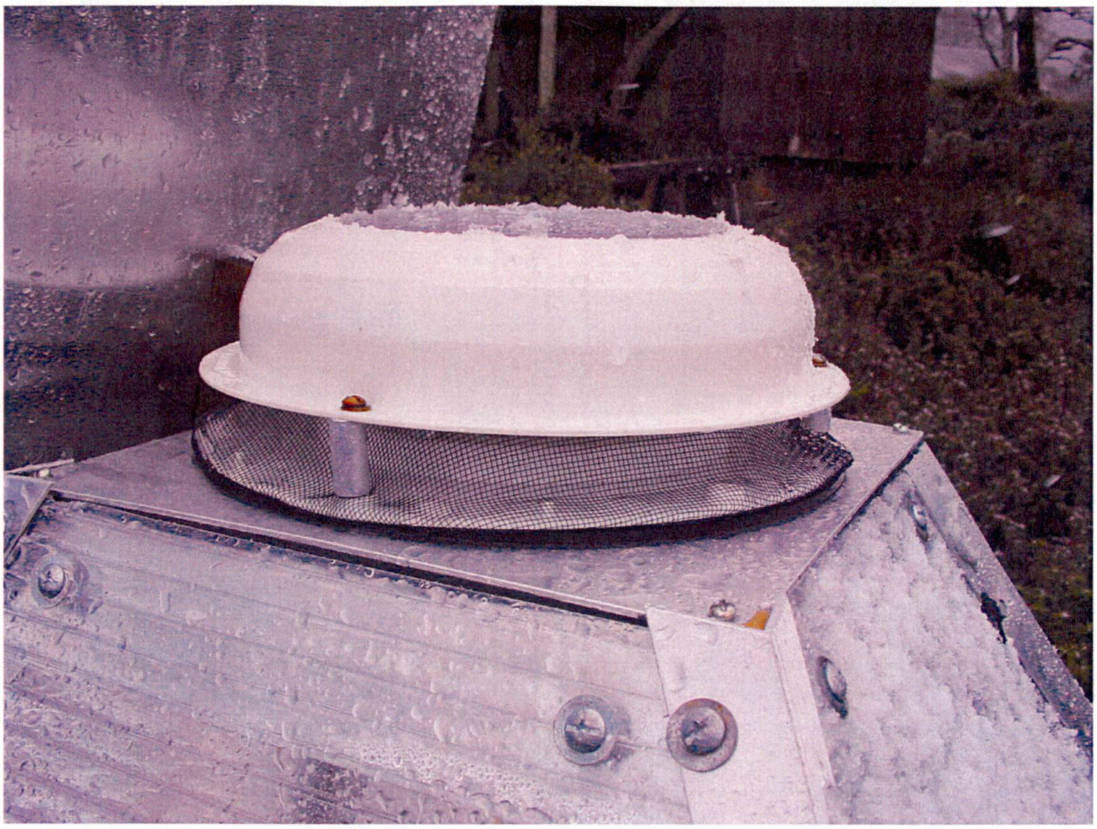

Plate 3.7 The modified ventilation unit attached to the field test evaporator

3.6.4 THE EFFLUENT CONTAINMENT VESSEL

A $1m^2$ by 300mm deep black polyethylene tub was used to contain the effluent. This incorporated reinforced side panels to reduce bowing when heated by solar radiation and included an overflow pipe to prevent the spilling of effluent during testing in the field. This tub was placed under the enclosure and the wick was located inside as demonstrated in Plate 3.6.

3.6.5 PRELIMINARY FIELD TEST EVAPORATOR TESTING METHOD

The method employed for preliminary testing of the field test evaporator design at the University of Tasmania utilised the same pointer system, evaporative medium (water) and control used to test the prototype.

3.7 TESTING PHASE FOUR: FIELD TESTING AT LAKE DOBSON GOVERNMENT HUTS IN THE MT FIELD NATIONAL PARK

Following a preliminary testing regime the evaporator was moved to Lake Dobson in the Mt Field National Park for connection to the composting toilet facility located at the Government Huts accommodation. The connection is described below.

3.7.1 FIELD TESTING METHOD

The field-testing method did not make use of a control. A tipping bucket rain gauge was used to measure the effluent entering the unit. The capacity of the bucket was determined by calculating the area of the rain gauge inlet and combining this figure with the knowledge that one tip equated to .25mm depth of water across this surface area (See Appendix B). A data logger was used to record the number of tip events over time. In order to estimate the amount of effluent residing in the containment vessel at the time of each visit to the testing site at Mt Field a tape measure was used. This was attached to the wick frame and butted against the bottom of the tub to indicate the depth of the effluent, this depth, and the dimensions of the tub, were used to calculate the amount of effluent inside. This figure, combined with the tipping bucket measurement was used to calculate the amount of effluent evaporated over each testing period. These periods varied due to the weather restricting access to the site but were in the order of approximately two weeks. The effluent volume data were matched to the number of toilet visits, measured using a "TRAKER" heat sensor, to estimate the amount of liquid effluent entering the evaporator per toilet visit. The heat sensor was placed close to the entrance to the toilet facilities at a height allowing for the heat escaping from the heads of toilet users to trigger an event. The unit has a display and the figure indicated was halved to approximate the number of toilet users based on the fact that each user would have to pass by the unit twice for each toilet visit.

Data loggers were used to record the temperature of the water and air inside the evaporator and the ambient air temperature outside. This information was used to determine the effectiveness of the evaporator in trapping heat and to compare the rate of evaporation to the various temperature readings.

3.7.2 THE CONNECTION

Plate 3.8 The connection to the composting toilet at Government Huts

Several components were used to connect the field test evaporator to the composting toilet at Government Huts as depicted in Plate 3.8. A drain removed liquid effluent from the compost batch tank and transferred it to the evaporator via a poly-pipe. The pipe was hidden under the timber running from the lower level of the toilet structure (compost pile) to the left foreground in Plate 3.8. This pipe was supplying the effluent to a NPWS designed evaporator but was diverted to run into the field test evaporator via the tipping bucket arrangement. The tipping bucket rain gauge was contained within the white box adjacent to the field test evaporator and used to measure the flow of effluent as described above. This is pictured in Plates 3.8 and 3.9.

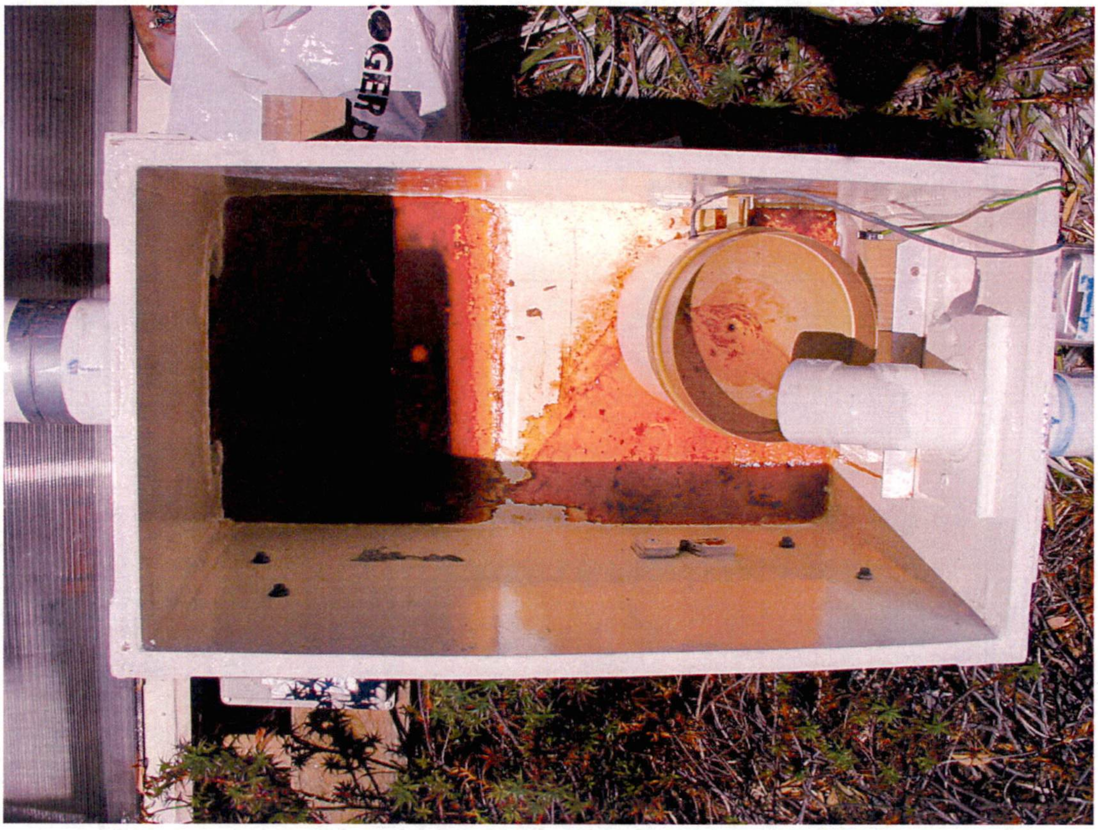

Plate 3.9 The field test evaporator tipping bucket rain gauge

3.7.3 CONCLUSION

Chapter 3 has outlined the methodology and design aspects of this thesis. Testing Phase One, conducted in the laboratory, indicated that the use of a wick and a fan aided evaporation. These findings were incorporated into the design of a prototype evaporator in Testing Phase Two and compared with a control indicating that their use, along with maximising subsequent heat uptake, would facilitate an effective evaporator. Over the duration of the prototype modification and testing regime it became apparent that the tube air inlet system failed to take advantage of wind movement to aid evaporation. Accordingly, during Testing Phase Three the field test evaporator inlets were designed to take advantage of natural wind movement. Furthermore, the performance gains achieved through adding a window to the prototype prompted the change to a clear outer shell for the field test evaporator along with black wick material to absorb the extra light entering the unit. The field test evaporator was evaluated at the University prior to the commencement of Testing Phase Four at Lake Dobson Government Huts composting toilet facility in the Mt Field National Park. Chapter 4 will present the results from the prototype and field-testing regimes outlined in the above chapter.

CHAPTER 4

Results

The results relating to the various guises of the prototype evaporator are presented in this chapter. Results for: preliminary outdoor testing of the field test evaporator at the University of Tasmania are then presented, and finally the results of the field testing of the field test evaporator at Lake Dobson Government Huts in Tasmania's Mt Field National Park.

4.1 PROTOTYPE TESTING RESULTS

Table 4.1 summarises both the configuration tested and the results gathered from Prototype Evaporator test 1.0.

Configuration Prototype version 1.0					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
No	1	Yes	No	No	No
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 1.0**
14/05/01	11.30 am	19	74	full	full
15/05/01	12.00 noon	15.5	81	0	0
16/05/01	4.40 pm	17.5	65	175	0
17/05/01	2.00 pm	13	72	550	0
Total Evaporation				**725**	**0**

Table 4.1 Results from Prototype Evaporator Test 1.0

*R/H% = Relative Humidity expressed as a percentage.

The table shows that the Prototype achieved no evaporation and the test was subsequently abandoned after 3 days.

Table 4.2 presents both the configuration and the results from Prototype Evaporator Test 1.1. The black plastic outer shell was modified from test 1.0 to accommodate two more inlet hoses as a lack of inlet area was suspected as the cause of failure in the initial test.

Configuration Prototype version 1.1					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
No	3	Yes	No	No	No
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 1.1**
18/05/01	3.30 pm	15.5	77	full	full
21/05/01	1.15 am	16.5	72	250	525
22/05/01	12.00 noon	14	80	0	0
24/05/01	10.45 am	15.75	72	100	290
25/05/01	4.12 pm	15	82	220	0
28/05/01	3.40 pm	16	77	180	270
29/05/01	1.20 pm	16	81	50	0
30/05/01	2.00 pm	15.25	91	0	0
31/05/01	4.10 pm	13.5	75	250	285
01/06/01	4.20 pm	11	75	110	0
03/06/01	4.20 pm	12.5	72	175	300
Total Evaporation				**1335**	**1670**
Performance Ratio Prototype 1.1: Control 1 = 1.25:1					

Table 4.2 Results from Prototype Evaporator Test 1.1

*R/H% = Relative Humidity expressed as a percentage.

Prototype 1.1 generally performed poorly on high humidity days as demonstrated on 25/05/01. On 29/05/01, a day of high humidity, and 01/06/01, a day of low temperature and moderate humidity the control evaporator outperformed the prototype. However, on the days where the prototype facilitated any evaporation it outperformed the control. The performance ratio indicated that the prototype produced more evaporation than the control over the full range of conditions encountered in this test.

Table 4.3 presents the results from Prototype Evaporator Test 2.0. Table 4.4 indicates the average water and air temperatures inside the control and Prototype version 2.0 evaporators.

Configuration Prototype version 2.0					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
No	3	Yes	Yes	No	No
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 2.0**
27/07/01	1.30 pm	15.5	59	full	Full
28/07/01	8.10 am	8	87	0	125
29/07/01	2.05 pm	16	67	140	375
30/07/01	11.45 am	16	62	50	0
31/07/01	10.10 am	12.5	79	125	0
01/08/01	12.50 pm	13	69	250	225
02/08/01	5.50 pm	14.5	57	0	225
03/08/01	4.23 pm	15.25	58	240	0
04/08/01	1.35 pm	16	63	110	225
Total Evaporation				**915**	**1175**
Performance Ratio Prototype 2.0: Control 1 = 1.28:1					

Table 4.3 Results from Prototype Evaporator Test 2.0

*R/H% = Relative Humidity expressed as a percentage.

On three occasions the control achieved some level of evaporation while the prototype did not. On 28/07/01, the coldest and most humid day of this test, the prototype evaporated 125mL, while the control elicited no measurable evaporation. The performance ratio indicated that overall the prototype outperformed the control by a slightly higher ratio than in test 1.1.

	Prototype version 2.0		**Control 1**	
	Water	**Air**	**Water**	**Air**
Average Temperature (°C)	11.62	11.03	15.12	15.48
			Water	**Air**
Average Temperature Ratio Prototype 2.0: Control 1			1:1.30	1:1.40

Table 4.4 Average water and air temperatures for Evaporator Test 2.0

The average temperatures of both the water and air in the control were higher than that of the prototype version 2.0.

Table 4.5 presents the results from Prototype Evaporator Test 3.0 and Table 4.6 indicates the average water and air temperatures inside the control and Prototype version 3.0 evaporators along with ratios of these temperatures.

Configuration Prototype version 3.0					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
Yes	3	Yes	Yes	No	No
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 3.0**
07/08/01	5.20 pm	15	56	full	Full
08/08/01	3.40 pm	15	58	0	655
09/08/01	2.45 pm	17	55	75	0
10/08/01	3.30 pm	15	56	275	450
11/08/01	1.54 pm	18	42	150	350
12/08/01	1.44 pm	14.5	57	120	0
13/08/01	2.42 pm	15	47	180	450
14/08/01	1.31 pm	16.5	64	0	0
15/08/01	3.30 pm	15.25	53	570	620
16/08/01	2.57 pm	15.25	81	0	225
Total Evaporation				**1370**	**2750**
Performance Ratio Prototype 3.0: Control 1 = 2.007:1					

Table 4.5 Results from Prototype Evaporator Test 3.0
*R/H% = Relative Humidity expressed as a percentage.

On 09/08/01 and 12/08/01 the control evaporator outperformed the prototype version 3.0 in conditions of moderate humidity and warm ambient temperature. On 16/08/01, a day of high humidity, the prototype evaporated 225mL of water compared to no measurable evaporation from the control. The overall performance ratio comparison reflects a significant performance increase for the prototype version 3.0 over the prototype configuration in the previous test.

	Prototype Version 3.0		Control 1	
	Water	**Air**	**Water**	**Air**
Average Temperature (°C)	14.04	13.86	15.30	14.95
			Water	**Air**
Average Temperature Ratio Prototype 3.0: Control 1			1:1.09	1:1.08

Table 4.6 Average water and air temperatures for Evaporator Test 3.0

The average water and air temperatures inside the control are higher than those of the prototype, however, the relative temperature difference between the two decreased with the prototype configured as version 3.0 compared to the previous test.

Table 4.7 presents the results from Prototype Evaporator Test 4.0 and Table 4.8 indicates the average water and air temperatures inside the control and Prototype version 4.0 evaporators along with ratios of these temperatures.

Configuration Prototype version 4.0					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
Yes	3	No	No	Yes	No

				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 4.0**
10/10/01	5.17 pm	17.25	58	full	Full
11/10/01	5.14 pm	18.55	69	250	425
12/10/01	5.08 pm	13.5	67	0	0
13/10/01	5.25 pm	17.25	67	0	0
14/10/01	5.06 pm	15	58	190	240
15/10/01	5.35 pm	16	59	185	515
16/10/01	5.36 pm	13.75	53	0	290
17/10/01	5.08 pm	16.75	46	410	410
18/10/01	5.08 pm	8.75	81	150	475
19/10/01	5.24 pm	11.75	65	160	500
20/10/01	5.19 pm	17	46	260	590
21/10/01	5.20 pm	17	56	320	560
22/10/01	5.40 pm	22.5	50	375	710
23/10/01	5.10 pm	25.5	29	410	600
24/10/01	5.25 pm	20	66	75	475
Total Evaporation				**2785**	**5790**
Performance Ratio Prototype 4.0: Control 1= 2.079:1					

Table 4.7 Results from Prototype Evaporator Test 4.0
*R/H% = Relative Humidity expressed as a percentage.

On all test days prototype 4.0 evaporated the same or more than the control. On 18/10/01, a day of cool ambient air temperature and high humidity, both evaporators facilitated some evaporation. The prototype version 4.0 evaporated 475mL of water, 3.176 times the evaporation of the control. Similarly, on the 19/10/01, a day of cold ambient air temperature, the prototype version 4.0 evaporated 500mL of water, 3.125 times the evaporation of the control. On 23/10/01, a day of relatively low humidity and warm ambient air temperature the prototype version 4.0

achieved 600mL of evaporation compared to 410 for the control amounting to a performance ratio of 1.463:1 in favour of the prototype version 4.0.

	Prototype Version 4.0		**Control 1**	
	Water	**Air**	**Water**	**Air**
Average Temperature (°C)	16.94	16.60	18.87	17.95
			Water	**Air**
Average Temperature Ratio Prototype 4.0: Control 1			1:1.11	1:1.08

Table 4.8 Average water and air temperatures for Evaporator Test 4.0

The average temperature of the water and air inside the prototype evaporator was lower than that of the control. The temperature ratios indicate that the control was relatively hotter than the prototype when compared to the previous test.

Table 4.9 presents the results from Prototype Evaporator Test 5.0 and Table 4.10 indicates the average water and air temperatures inside the control and Prototype version 5.0 evaporators along with ratios of these temperatures.

Configuration Prototype version 5.0					
Window	Air Inlets	Solar Ventilator	Reflector	Small Wick	Large Wick
Yes	3	Yes	Yes	Yes	No
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 5.0**
30/08/01	2.35 pm	15	67	Full	Full
31/08/01	3.04 pm	14	67	125	375
01/09/01	3.16 pm	14.5	62	0	190
02/09/01	3.14 pm	15.5	63	150	335
03/09/01	3.35 pm	18	51	210	630
04/09/01	3.19 pm	13.5	55	225	675
05/09/01	2.10 pm	14.5	62	100	125
06/09/01	3.24 pm	17.75	47	200	390
07/09/01	3.10 pm	18	53	75	365
08/09/01	2.56 pm	17.5	42	100	270
09/09/01	2.55 pm	15	67	240	425
10/09/01	3.07 pm	15.5	75	115	445
11/09/01	3.23 pm	17.5	60	150	610
12/09/01	2.57 pm	19	54	200	550
13/09/01	2.58 pm	19.25	56	250	545
Total Evaporation				**2140**	**5930**
Performance Ratio Prototype 5.0: Control 1= 2.771:1					

Table 4.9 Results from Prototype Evaporator Test 5.0

*R/H% = Relative Humidity expressed as a percentage.

At no time during this testing period did the control outperform the prototype evaporator and the prototype version 5.0 produced evaporation on all days. The highest humidity reading was taken on 10/09/01 indicating the prototype evaporation at 3.87 times that of the control on this day. On 04/09/01, the coldest recorded ambient temperature, the prototype outperformed the control by a ratio of 3:1; on 13/09/01, the hottest recorded ambient temperature, the performance ratio was 2.18:1 in favour of the prototype. The overall performance ratio advantage to the prototype evaporator was considerably higher than that recorded in the previous test and test 3.0 where the configuration was the same except for the absence of the wick.

	Prototype Version 5.0		**Control 1**	
	Water	**Air**	**Water**	**Air**
Average Temperature (°C)	14.83	14.47	16.31	16.45
			Water	**Air**
Average Temperature Ratio Prototype 5.0: Control 1			1:1.10	1:1.14

Table 4.10 Average water and air temperatures for Prototype Evaporator Test 5.0

The average water and air temperatures for the control 1 evaporator were higher than that of the prototype in this test. Despite the increased evaporation from prototype 5.0 the temperature ratios are very close to that of tests 3 and 4.

Table 4.11 presents the results from Prototype Evaporator Test 6.0 and Table 4.12 indicates the average water and air temperatures inside the control and Prototype version 6.0 evaporators along with ratios of these temperatures.

Configuration Prototype version 6.0					
Window	Air Inlets	Solar ventilator	Reflector	Small Wick	Large Wick
Yes	3	Yes	Yes	No	Yes
				Evaporation	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Prototype 6.0**
30/10/01	5.00 pm	14.25	74	Full	Full
31/10/01	5.15 pm	14	49	240	640
01/11/01	4.57 pm	18	46	125	510
02/11/01	4.47 pm	14.5	57	225	710
03/11/01	5.15 pm	18.5	61	325	875
04/11/01	6.05 pm	23	44	375	1050
05/11/01	4.55 pm	17.75	80	350	640
06/11/01	4.58 pm	13.25	73	0	135
07/11/01	5.11 pm	12.5	63	0	600
08/11/01	5.07 pm	16.25	70	300	700
09/11/01	5.05 pm	18.5	51	360	900
10/11/01	4.58 pm	13.25	50	200	800
11/11/01	5.04 pm	15	53	350	845
12/11/01	4.58 pm	16	83	0	0
13/11/01	5.09 pm	19	51	350	605
Total Evaporation				**3200**	**9010**
Performance Ratio Prototype 6.0: Control 1= 2.816:1					

Table 4.11 Results from Prototype Evaporator Test 6.0

*R/H% = Relative Humidity expressed as a percentage.

On 12/11/01, a day of relatively high humidity, no measurable evaporation occurred from either evaporator. On 07/11/01, the day with the coldest recorded ambient air temperature and moderate humidity, the prototype version 6.0 evaporated 600mL compared to the control with no measurable evaporation. The overall performance ratio of 2.816:1 in favour of the prototype version 6.0 is significantly higher than that of the previous test.

	Prototype Version 6.0		**Control 1**	
	Water	**Air**	**Water**	**Air**
Average Temperature (°C)	Error*	15.86	17.99	18.32
			Water	**Air**
Average Temperature Ratio Prototype V. 6.0: Control 1			Error*	1:1.16

Table 4.12 Average water and air temperatures for Evaporator Test 6.0

* Error indicates data logger failure.

The air temperature performance ratio shows a similarity to tests 3, 4 and 5. The water temperatures cannot be compared due to data logger error.

4.2 FIELD TEST EVAPORATOR RESULTS FROM TESTING CONDUCTED AT THE UNIVERSITY OF TASMANIA

Table 4.13 presents the results from Field Evaporator Test 1.0 and Table 4.14 indicates the average water and air temperatures inside the control and field evaporators along with ratios of these temperatures.

				Evaporation (mL)	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Field Evaporator**
17/05/02	5.00 pm	14.25	59	full	Full
18/05/02	4.00 pm	13	67	255	2800
19/05/02	3.58 pm	13.25	62	95	1310
20/05/02	4.00 pm	12.75	75	0	1160
21/05/02	6.07 pm	13	69	70	1205
22/05/02	4.05 pm	13.75	53	95	1800
23/05/02	3.52 pm	12.5	56	65	1600
24/05/02	5.00 pm	10.25	83	25	1625
25/05/02	4.00 pm	14.25	61	150	1575
26/05/02	7.21 pm	12.25	77	0	1825
27/05/02	4.22 pm	13.5	59	100	2075
28/05/02	4.07 pm	13.5	63	70	1825
29/05/02	4.03 pm	13	54	150	2300
30/05/02	3.50 pm	14.5	49	40	2300
31/05/02	4.10 pm	14.5	81	100	1750
Total Evaporation				**1215**	**25150**
Performance Ratio per m^2 of water surface area* **Field Evaporator: Control 1 = 3.726:1**					

Table 4.13 Results from Field Evaporator Test 1.0

*R/H% = Relative Humidity expressed as a percentage.

*Performance ratio per m^2 of water surface area compares the effluent containment vessel area of the control to that of the field evaporator.

On 24/05/02, the day of coldest recorded temperature and highest recorded humidity, the field test evaporator evaporated 1625mL of water compared to the control figure of 25mL; this, when adjusted for tub surface area, represents a performance ratio of 11.7:1 in favour of the field test design.

		Field Evaporator		Control 1	
	Ambient	**Water**	**Air**	**Water**	**Air**
Average Temperature (°C)	11.71	14.68	10.56	15.81	12.87
				Water	**Air**
Average Temperature Ratio Field Evaporator: Control 1				1:1.08	1:1.22

Table 4.14 Average water and air temperatures for Field Evaporator Test 1.0

The temperature data in Table 4.14 indicates that the water and air temperatures in the field test evaporator were lower than those in the control. Average air temperatures in the Field Test Evaporator were lower than ambient while internal water temperatures were above ambient.

Table 4.15 presents the results from Field Evaporator Test 2.0 and Table 4.16 indicates the average water and air temperatures inside the control and field evaporators along with ratios of these temperatures. No modifications were made to the field test evaporator from Field Evaporator Test 1.0.

				Evaporation (mL)	
Date	**Time**	**Temp (°C)**	**R/H%***	**Control 1**	**Field Evaporator**
17/06/02	4.20 pm	11	66	Full	Full
18/06/02	4.07 pm	10.75	57	0	1390
19/06/02	4.04 pm	9.75	64	0	1230
20/06/02	3.58 pm	10.5	71	200	3015
21/06/02	4.18 pm	14	49	85	2980
22/06/02	3.28 pm	14.5	51	265	4795
23/06/02	4.14 pm	14.5	49	80	2220
24/06/02	4.24 pm	16.75	49	200	3480
25/06/02	4.28 pm	11	69	200	4300
26/06/02	4.24 pm	12.5	53	125	2450
27/06/02	4.25 pm	11	63	0	2375
28/06/02	4.02 pm	9	63	155	1270
29/06/02	4.30 pm	11.75	73	0	1420
30/06/02	7.30 pm	12.5	69	235	1075
01/07/02	4.23 pm	14.25	61	0	2875
Total Evaporation				**1545**	**34875**
Performance Ratio per m^{2} of water surface area*				**Field Evaporator: Control 1 = 4.063:1**	

Table 4.15 Results from Field Evaporator Test 2.0

*R/H% = Relative Humidity expressed as a percentage.

*Performance ratio per m^{2} of water surface area compares the effluent containment vessel area of the control to that of the field evaporator.

The day of greatest performance advantage over the control was 01/07/02 with 2875mL evaporated by the field test evaporator and no evaporation from the control. The conditions on this day were relatively warm with moderate humidity. The other days where the control failed to perform at all were relatively cold with moderate to high humidity.

		Field Evaporator		Control 1	
	Ambient	**Water**	**Air**	**Water**	**Air**
Average Temperature (°C)	10.73	13.95	9.15	14.20	11.45
				Water	**Air**
Average Temperature Ratio Field Evaporator: Control 1				1:1.32	1:1.25

Table 4.16 Average water and air temperatures for Field Evaporator Test 2.0

The average temperature ratios for Field Evaporator Test 2.0 differ slightly from the previous test in that the water temperature ratios are comparatively higher in favour of the control yet the air temperature ratios are similar. Air temperatures were again greater than ambient for the control but lower than ambient for the evaporator.

4.3 FIELD TEST EVAPORATOR RESULTS FROM TESTING CONDUCTED AT THE GOVERNMENT HUTS ACCOMMODATION COMPOSTING TOILET IN THE MT FIELD NATIONAL PARK, TASMANIA

Table 4.17 provides the results from the Field Evaporator Trial 1.0 conducted from December 19, 2002 to January 06, 2003.

Number of toilet uses					287
Average number of uses per day					15.9
Average volume expelled to evaporator per use					0.032 **L**
Average daily effluent output to evaporator					0.511 **L**
Total effluent output from toilet to evaporator					9.197 **L**
Total evaporation					9.197 **L**
Average wind speed (Maydena)					4.56 **km/h**
	Maydena*		**Field Test Evaporator**		**Ambient**
	Max	**Min**	**Internal air**	**Internal water**	
Average temperature (°C)	23.6	10.55	20.879	16.353	15.605
Maximum temperature (°C)	30.3		59.900	30.940	26.52
Minimum temperature (°C)	7.1		-2.440	8.240	8.75

Table 4.17 Results from Field Evaporator Trial 1.0

*Maximum, minimum, and averages of these are from weather data recorded at Maydena weather station (the nearest station to the test site). Weather data are only available for 8 of the minimum and 9 of the maximum temperatures for the period.

Table 4.18 provides the results from the Field Evaporator Trial 2.0 conducted from January 06 to January 23, 2003.

Number of toilet uses				357
Average number of uses per day				20.9
Average volume expelled to evaporator per use				.053 **L**
Average daily effluent output to evaporator				1.114 **L**
Total effluent output from toilet to evaporator				18.938 **L**
Total evaporation				14.938 **L**
Average wind speed (Maydena)				18.03 **km/h**
	Maydena		**Field Test Evaporator**	
	Max	**Min**	**Internal air**	**Internal water**
Average temperature (°C)	25.07	9.4	21.330	15.882
Maximum temperature (°C)	32.8		56.500	26.160
Minimum temperature (°C)	4.6		1.600	8.070

Table 4.18 Results from Field Evaporator Trial 2.0

Figure 4.1 indicates that the effluent load to the evaporator was heaviest just prior to the end of the test peiod.

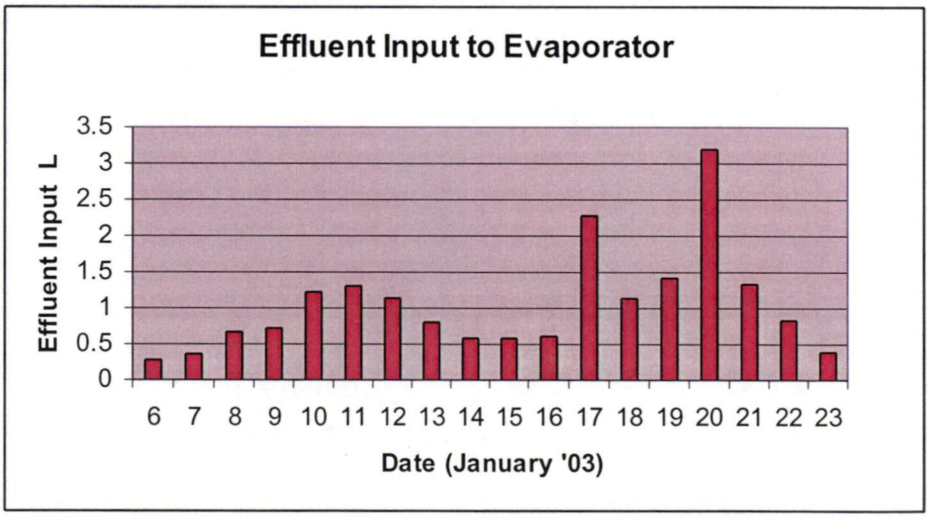

Figure 4.1 Daily effluent input to evaporator for Test Period Jan 06 to 23

Table 4.19 provides the results from the Field Evaporator Trial 3.0 conducted from January 23, 2003 to February 06 2003.

<table>
<tr><td colspan="4">Number of toilet uses</td><td>174</td></tr>
<tr><td colspan="4">Average number of uses per day</td><td>12.4</td></tr>
<tr><td colspan="4">Average volume expelled to evaporator per use</td><td>0.056 L</td></tr>
<tr><td colspan="4">Average daily effluent output to evaporator</td><td>0.691 L</td></tr>
<tr><td colspan="4">Total effluent output from toilet to evaporator</td><td>9.676 L</td></tr>
<tr><td colspan="4">Total evaporation</td><td>9.676 L</td></tr>
<tr><td colspan="4">Average wind speed</td><td>4.62 km/h</td></tr>
<tr><td></td><td colspan="2">Maydena</td><td colspan="2">Field Test Evaporator</td></tr>
<tr><td></td><td>Max</td><td>Min</td><td>Internal air</td><td>Internal water</td></tr>
<tr><td>Average temperature* (°C)</td><td>25.9</td><td>9.06</td><td>21.758</td><td>15.761</td></tr>
<tr><td>Maximum temperature* (°C)</td><td colspan="2">34.9</td><td>63.480</td><td>27.060</td></tr>
<tr><td>Minimum temperature* (°C)</td><td colspan="2">4.6</td><td>-0.61</td><td>6.18</td></tr>
</table>

Table 4.19 Results from Field Evaporator Trial 3.0

*Maximum, minimum, and averages of these are from weather data recorded at Maydena weather station (the nearest weather station to the test site). Weather data are only available for 13 of the 14 minimum and maximum temperatures for the period.

4.3.1 OBSERVATIONS

The installation of the Field Test Evaporator was completed on 19/07/02. Problems were encountered with measuring effluent outflow and use numbers simultaneously, and hence results for these parameters are only available from 19/12/02 to 23/01/03. The Field Test Evaporator continued to service the toilets at Government Huts up to August 2004 and observations indicated that the evaporation rates were sufficient to handle all conditions and loads offered at this facility. This was clear because the overflow facility had not been utilised.

CHAPTER 5

Discussion

In order to assess the effectiveness of individual design parameters it is necessary to examine the data gathered at each stage of testing and compare the results from one test to another. The increase in performance with each physical change to prototypes is discussed in light of the theoretical considerations discussed in Chapter 2. The performance of the field trial is then examined. Finally, aerobiological considerations are examined.

5.1 PROTOTYPE TESTING

Figure 5.1 (see page 64) provides a graphical summary of the performance ratios determined for each stage of testing at thc Univcrsity of Tasmania. This serves as a reference point for the discussion.

Initially the Prototype evaporator failed to achieve any measurable evaporation as depicted in the results from Prototype Evaporator Test 1.0. This situation was attributed to the combination of high internal relative humidity and insufficient airflow. The resulting rapid saturation of the air above the internal body of water led to the cessation of the evaporation process.

An increase in the inlet area for version 1.1 in Prototype Test 1.1 provided greater airflow and initiated the evaporation process despite the presence of high ambient relative humidity. The performance comparison between version 1.1 and the Control indicated that the overall evaporation for the Prototype was greater. However, days of very high humidity and/or low temperature were favouring the Control design. The likelihood of such days being heavily overcast gave rise to a theory that the poor performance on some humid days may be due to insufficient light entering the PV cells to commence movement of the fan.

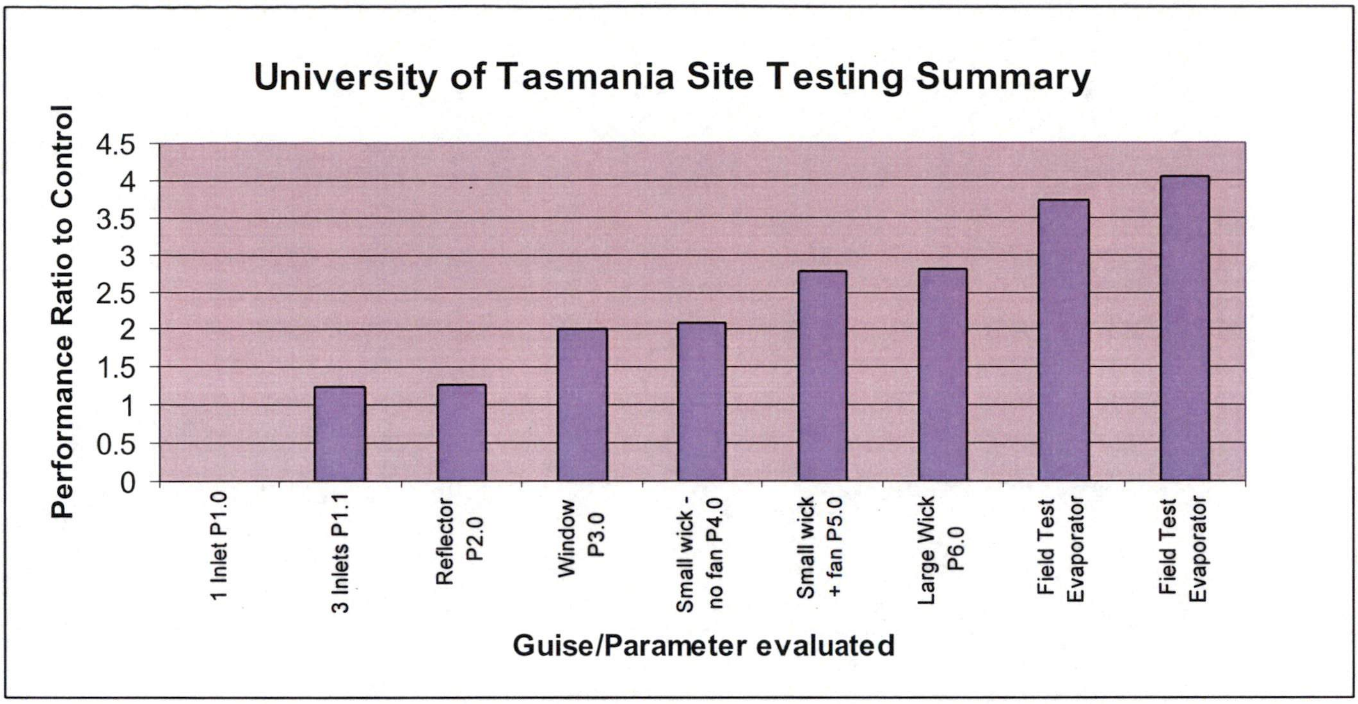

Figure 5.1 A summary of the testing on site at the University of Tasmania

Prototype Evaporator Test 2.0 used a reflector to increase solar insolation to the photovoltaic cells powering the fan and resulted in improved performance comparisons with the control on some colder/more humid days. The data seems to support the theory formulated in test 1.1 regarding a lack of solar insolation contributing to the performance deficit to the control in heavily overcast conditions. At this point the Control configuration was still outperforming the Prototype v 2.0 on some days. This was attributed to the superior heat gaining and holding properties of the Control.

Prototype Evaporator Test 3.0 indicated that light penetration into the unit provided by the addition of a window on the north facing side narrowed the water and air temperature differential between the Control and Prototype version 3.0. This modification afforded a significant overall performance increase that can clearly be seen in Figure 5.1. However, the Control still outperformed Prototype version 3.0 on some days, in this case on days of low ambient humidity.

Increased surface area was introduced for Prototype Evaporator Test 4.0. Though no fan was operating, version 4.0 provided an increased performance ratio advantage over the control to that of the previous test. This indicated that the larger evaporative surface area made available by the introduction of a pure cotton wick material increased evaporative efficiency. The performance ratio comparison from tests 3.0 to 4.0 indicated that cold/low humidity weather performance of the prototype was improved despite version 4.0 having no fan.

Prototype version 5.0 involved the introduction of the solar powered fan to the configuration of Prototype Evaporator Test 4.0 and showed that the combination of fan and wick outperformed the Control in all the conditions encountered for the first time. On days of moderate temperature and humidity (i.e. 67% humidity and 13-14°C) the experiment conducted using the prototype without a fan (version 4.0) provided an evaporative performance ratio with the control of 1:1; the same unit with a fan (version 5.0) achieved a 3:1 ratio in favour of the prototype in similar conditions. Increased air movement afforded a relative reduction in the average air temperature of the prototype compared to both ambient conditions and the control. This can be attributed to the process of adiabatic cooling. Analysis of versions 4.0 and 5.0 (see Table 4.8 and 4.10) show that the parity of evaporation performance present in the test with no fan in these conditions was overcome and a clear evaporative performance improvement demonstrated with the introduction of the solar fan.

Prototype version 6.0 involved the change from the small wick used in version 5.0 to a large wick. The greater surface area afforded through this change resulted in a modest performance ratio comparison increase over version 5.0. However, the larger wick appears to elicit good performance in conditions of cooler temperature such as those encountered on 6, 7 and 10 November (See Table 4.11). The characteristics of minimal overall performance increase can be attributed to the fact that although more wick surface area was present in this configuration it is only the extent to which the wick is wet that increases the water surface area. Cooler, more humid days were consistently observed to result in greater wick saturation than warmer days. Gravity is the main limiting factor on the extent of saturation when adding increased vertical wick surface area. Accordingly, the addition of wick surface area to an evaporator is more effective if it is done in a manner where the increase in area is horizontal or parallel to the surface of the water because the degree to which it is saturated is not limited by this effect.

5.2 FIELD TEST EVAPORATOR TESTING AT THE UNIVERSITY OF TASMANIA

The field test evaporator tests conducted at the University of Tasmania depicted in sections 4.2 of the Results Chapter indicated that this design elicited good evaporative performance ratio comparisons with the control. Performance was good even on cold days of high humidity such as 24 May. This is also evident on 20 and 26 May and 29 July. Test 2.0, conducted in lower average daily ambient temperatures supports this low temperature/high humidity performance advantage theory with a higher performance ratio over that of the control for the testing period. The day of greatest ratio comparison advantage over the control elicited by the field test evaporator was that of 1 July where temperatures were well above average for the test with only moderate humidity. However, there appears to be no direct relationship between performance and ambient temperature and humidity as depicted on 25 and 26 July. This suggests that factors other than temperature and humidity such as the wind speed and direction influenced performance.

5.3 FIELD TEST EVAPORATOR TESTING AT THE GOVERNMENT HUTS ACCOMODATION COMPOSTING TOILET FACILITY IN THE MT FIELD NATIONAL PARK, TASMANIA

The in-the-field testing of the field test evaporator provided data indicating that the average liquid effluent entering the unit per toilet use was 47mL. This would indicate that unless people were going to the toilet 20 times per day or urinating elsewhere (unlikely at this location) the pile was absorbing and evaporating a significant proportion of the liquid from each toilet visit. Such observations are particularly significant to the process of matching effluent output to evaporator design and sizing in that the extent to which a compost pile will both absorb and evaporate urine will influence the effluent output to the evaporator. The batch compost toilets located at this facility were much larger than would be necessary for domestic use and demonstrate significant liquid absorption and/or evaporation properties. A smaller batch system may present a more linear input/output flow.

Ambient temperature figures were only available for Field Evaporator Trial 1.0 due to data logger failure. The average ambient temperature is lower than that of the internal water and internal air temperatures of the evaporator. These average figures were influenced by the solar heat gain attributes of the design and the thermal mass properties of the effluent. All three testing periods were characterised by minimum internal temperatures that were significantly lower than those of the ambient, suggesting that considerable adiabatic cooling was taking place. Of particular interest was the fact that this was occurring at night. This would suggest that wind velocity through the unit was playing a significant role in the evaporation of the liquid effluent. Upon this realisation it became apparent that the use of wind as a catalyst for evaporation in this context was a design consideration worth further exploration. This thesis does not however, further explore this avenue.

Though only two testing periods are depicted in the results for the field fest evaporator trial at Mt Field, the period of service to this facility was over twelve months in duration. The overflow facility on the field test evaporator was not used during this period. In fact, the effluent reservoir was never more than half full. This was evident from the deposit of encrusted salts and solids at the high effluent mark. This indicated that the matching of evaporator capacity to effluent output was appropriate for the weather conditions present over the 12-month period.

5.4 AEROBIOLOGICAL CONSIDERATIONS

The key aerobiological considerations relevant to the treatment of blackwater through solar evaporation are the extent to which bioaerosols containing pathogens are likely to be created and their viability once airborne.

Wave, splash and bubble bursting actions are outlined in chapter 2 as the key means by which bioaerosols are formed. The environment inside the solar evaporators designed and tested in the context of this thesis are not likely to create any of these three means of bioaerosol formation. The wick material acts as a baffle to alleviate the possibility of wave formation, the slow effluent input rate to the evaporator is not conducive to significant splash creation and no aeration or bubble-forming mechanisms are present. The most likely means by which bioaerosols are created in such an environment is through wind action during high wind velocity weather events. However, the relatively small evaporator inlets combined with the internal component design are unlikely to generate sufficient wave or splash action to release high numbers of bioaerosols.

Moreover, the studies into bioaerosol formation at compost facilities discussed in chapter two suggest that the wetting of compost piles reduces the extent of bioaerosol formation. Due to its relative dryness, the compost pile of a toilet facility seems to be more likely to produce bioaerosols than the evaporator itself, especially during pile turning. It is likely that relatively low levels of bioaerosols will be produced from the solar evaporators tested in this thesis.

The viability of the pathogen containing bioaerosols produced is also discussed in chapter 2. The key factors influencing viability are relative humidity, temperature and oxygen. To a lesser degree, solar irradiation and open-air factors are also relevant. The conditions present inside and around a solar evaporator of the design described in this thesis present a combination of most of the factors that reduce the viability of bioaerosols. Consequently, the number of viable pathogens released in this way from such a facility is likely to be minimal and once in the open air, the majority of survivors are highly likely to be rendered unviable almost immediately.

The compost pile appears to have a greater capacity than the evaporator to produce bioaerosols due to its drier nature. Compared to the likelihood of transfer of infection at a campsite of the introduction of liquid toilet effluent into ground or surface waters the aerobiological pathways for disease transmission appear to be minimal.

CHAPTER 6

Conclusion

Chapter 6 revisits the objectives and research questions presented in the introduction.

6.1 OBJECTIVES

6.1.1 OBJECTIVE ONE:

Conduct basic laboratory testing and a literary review for facilitating a greater understanding of the various aspects of evaporation and to identify the key considerations for liquid human waste management in remote cool temperature areas of Tasmania.

The review of literature concluded that most existing toilet use and infrastructure approaches in natural areas were failing to separate human faecal waste from the environment. This analysis identified the key impact of these failures on human health to be infection ensuing from exposure to various pathogens including bacteria, viruses, protozoa and helminths. The likely environmental implications were identified as: infection of local animals with parasitic zoonoses; the death, through nutrient loading, of native low nutrient adapted vegetation; and an increased likelihood of infiltration of high nutrient adapted exotic plant species.

Examination of the visual intrusion of toilet infrastructure on the natural landscape concluded that a design criterion of minimal visual impact sensitive to the national park aesthetic was appropriate. This outcome was reached through balancing the visual impact component necessary to employ the use of a solar evaporator with the human and environmental risks associated with the escape of liquid human effluent to the environment.

The review of relevant evaporation theory determined that the main factors affecting evaporation of water from a container are input of energy, water surface area, air movement and relative humidity gradient. The possibility of transport of microorganisms through the air was evaluated resulting in the conclusion that the use of a solar evaporator provided little risk of significant levels of airborne bacteria, viruses and fungal particles entering the local environment and causing infection.

Laboratory testing was undertaken in order to examine the various theoretical means of exploiting evaporation in a controlled environment and confirmed that cotton towelling material was effective in wicking moisture to increase water surface area and aid evaporation and that the introduction of air movement over the surface of a body of water elicited a significant increase in evaporation.

6.1.2 OBJECTIVE TWO:

Apply these basic principles and the results from laboratory testing to the design and construction of a prototype evaporator. Following this, conduct a testing regime involving the prototype tested against a control designed to simulate the performance of the existing National Parks and Wildlife evaporators.

The construction of a control to simulate the NPWS evaporator design and a prototype evaporator based on the key principles identified in the review of literature enabled a "real world" application of the key design components identified in the laboratory. This testing determined that the prototype evaporator could achieve greater efficiency than the control and provided an understanding of the limitations of the prototype design.

6.1.3 OBJECTIVE THREE:

Use the results from testing and observation to design and construct a final evaporator for testing in the field. Also, gather empirical evidence in the field to better enable the matching of toilet loads to evaporator size.

The design of the field test evaporator demonstrated the knowledge gained in the previous testing regimes by amending limitations of the prototype design and incorporating the successful elements of the prototype. The testing successfully demonstrated that the enhanced evaporation principles applied to this design could meet the evaporation needs of the composting toilet facility located at the Government Huts accommodation near Lake Dobson in the Mt Field National Park. Also, a method by which to collect data to evaluate the effluent output per person per toilet visit was determined.

6.2 RESEARCH QUESTIONS

6.2.1 QUESTION ONE:

Can the current NPWS evaporator design be replaced with a design that facilitates increased efficiency leading to reduced size and visual intrusion?

This thesis has clearly shown that this question can be answered in the affirmative as demonstrated by the significant difference between the 1.5m^2 base area of the field test evaporator and that of the NPWS design (approximately 10m^2) for which it provided a successful substitute for over twelve months. Also, the performance advantage offered by this design in cool and shaded conditions over the NPWS design enables the reduction of visual intrusion of this infrastructure on the natural landscape by providing siting flexibility.

6.2.2 QUESTION TWO:

Can empirical evidence be gathered and processed in order to properly match evaporator size to toilet loading?

Through the testing conducted at Mt Field a method for gathering empirical data for this matching process was developed. This enabled a figure for liquid effluent output to the evaporator per toilet use to be calculated. When matched to evaporative predictive modelling or data gathered at individual sites relating to evaporator performance this approach can be used to match evaporator size to toilet loading.

6.3 LIMITATIONS OF THE RESEARCH

The analysis of testing at the University of Tasmania was based on evaporation rates, temperature and humidity. It was obvious at times that the results were being affected by other parameters such as wind speed and solar insolation.

Though a figure for effluent output to the evaporator per toilet use was calculated it must be noted that the composting toilets at the Government Huts facility were close to capacity over this period and absorbency is likely to vary depending on toilet volume and loading.

Also, while flexibility in siting is offered due to the suitability of the field test evaporator design to cold and overcast conditions, maximum evaporation ensues from placement in direct sunlight to maximize solar insolation to the unit.

6.4 FURTHER RESEARCH

Further research could investigate the potential of the field test evaporator design for use in warmer climates with high humidity. These circumstances may cause algal growth that has not been encountered in high altitude testing and would provide interesting evaporation efficiency comparisons with the results presented in this thesis. Also, further development of the evaporator to take advantage of the obvious improvements in performance offered in windy conditions would be likely to improve overall efficiency and facilitate more evaporation in overcast conditions and at night.

References

American Society for Testing and Materials. 1969. *Manual on Water*. Third Edition. Easton, Md. USA.

Ariya, P.A. and Amyot, M. 2004, New Directions: The role of bioaerosols in atmospheric chemistry and physics, *Atmospheric Environment*, Vol.38, pp.1231-1232.

Awad, A.S., Ross, A.D., and Lawrie, R.A. 1989, *Guidelines for the Use of Sewage Sludge on Agricultural Land*, NSW Department of Agriculture and Fisheries.

Bauman, R.P. 1966, *An Introduction to Equilibrium Thermodynamics*, Prentice-Hall Inc., Englewood Cliffs, N.J.

Berry, G. 2000, Agricultural Sanitation: from Waste to Resource. PhD Thesis. School of Geography and Environmental Studies, University of Tasmania, Hobart, Tasmania.

Bitton, L.J. 1994, *Wastewater Microbiology*, Wiley-Liss, New York.

Bovallius, A., Bucht, B., Roffey, R. and Anas, P. 1978, Long-range air transmission of bacteria. *Applied Environmental Microbiology*, Vol. 35(6), pp.1231-1232.

Brassington, B.A. 1999, Wilderness Management: Human Waste and Water Quality. M.Env.Mgmt. Thesis, Centre for Environmental Studies, University of Tasmania, Hobart, Tasmania.

Brauns, J., 2000; How to Bushwalk, <http://www.tasmanian-ways.de/how.htm> [24/10/02]

Bridle, K.L. and Kirkpatrick, J.B. 2003, Impacts of nutrients additions and digging for human waste disposal in natural environments, Tasmania, Australia. *Journal of Environmental Management*, Vol 69, pp.299-306.

Bridle, K.L and Kirkpatrick, J.B. 2005, An analysis of the breakdown of paper products (toilet paper, tissues and tampons) in natural environments, Tasmania, Australia. *Journal of Environmental Management*, Vol.74, pp.21-30.

Burrows, B. 2000, in *Australian Alps Best PracticeHuman Waste Management Workshop*. Canberra and Jindabyne, Australia, March, p.31.

Bzowy, R. 1989, in *Proceedings of the Royal Australian Institute of Architect's Professional Development Program conference "Architecture in the Wild"*. Cradle Mountain, Tasmania, Australia, April, p.99.

Crennan, L. 1992, *Waste in troubled waters: a case for alternative sewage treatment*, Environmental Studies Working Paper Number 22, School of Geography and Environmental Studies, University of Tasmania, Hobart, Australia.

Crennan, L. 1995, Wet and Dry Conservancy: Politics and Practicalities of On-Site Sanitation. PhD Thesis, School of Geography and Environmental Studies, University of Tasmania, Hobart, Australia.

Critchfield, H.J. 1983, *General Climatology*, Fourth Edition. Prentice Hall, New Jersey.

Del Porto, D. and Steinfeld. 1999, *The Composting Toilet Book*. The Centre for Ecological Pollution Prevention, Massachusetts.

Dickson, M.T. 2000, Solar Composting Toilets. Honours Thesis. Centre for Environmental Studies, University of Tasmania, Hobart.

Drew, K. 1989, in *Proceedings of the Royal Australian Institute of Architect's Professional Development Program conference "Architecture in the Wild"*. Cradle Mountain, Tasmania, Australia, April, p.6.

Fordham, A. 1990, Pathogens in Sewage Sludge and Optimum Methods of Removal. *Effluent re-use Conference of Water Research Foundation of Australia*, Woolongong University, February 13-16.

Gerba, C.P., Wallis, C. and Melnick, J.L. 1975, Fate of wastewater bacteria and viruses in soil. *Journal Irrig. Drain. Div. A.S.C.E*, Vol.101, pp157-174.

Griffiths, W.D., Stewart, I.W., Clark, J.M. and Holwill, I.L. 1999, Procedures for the characterisation of bioaerosol particles. Part I: aerosolosation and recovery agent effects, *Aerobiologia* Vol 15, p.267-280.

Gotaas, H.B. 1956, *Composting – Sanitary Disposal and Reclamation of Organic Wastes*, World Health Organisation, Geneva, Switzerland.

Holman, D. and Todd, J., 2001, Solar Evaporation of Liquid Effluent from Composting Toilets, in *Proceedings of International Solar Energy Society 2001 Solar World Congress "Bringing Solar Down to Earth"*, Adelaide, Australia, 25-30 Nov.

Imshenetsky, A.A, Lysenko, S.V. and Kazakov, G.A., 1978, Upper Boundary of the Biosphere. *Applied Environmental Microbiology*, Vol 35(1) pp.1-5.

Jonsson, H., Richert Stintzing, A.Vinneras, B. and Salomon, E. 2004, Guidelines on the Use of Urine and Faeces in Crop Production. *EcoSanRes Publication Series. Report 2004-2*, Stockholmn Environment Institute, Stockholm, Sweden.

Lighthart, B. 1994, Physics of Microbial Aerosols, pp.5-27 in Lighthart, B. and Mohr, A.J (eds), *Atmospheric Microbial Aerosols, Theory and Applications*. Chapman and Hall, New York, N.Y.

Lighthart, B. and Mohr, A.J. 1994, *Atmospheric Microbial Aerosols: Theory and Applications*, Chapman and Hall, New York, N.Y.

Mohr, A.J. 2002, Fate and Transport of Microorganisms in Air, p.827-838, in Crawford, R.L., Hurst, C.J., Knudson, G.R., McInerney, M.J. and Stetzenbach, L.D. (eds), *Manual of Environmental Microbiology*, Second Edition, ASM Press, Washington, D.C.

Molland, O. 1982, Norway Introduces Quality Standards for Biological Toilets, A. Eikum and R. Seabloom (eds), *Alternative Wastewater Treatment*, D. Reidel Publishing Company, Holland.

Nichols, D.S., Prettyman, D., Gross, M. 1983, Movement of Bacteria and Nutrients from Pit Latrines in the Boundary Waters Canoe Area Wilderness, *Water, Soil and Air Pollution*, Vol. 20, pp.171-180.

Oke, T.R. 1978, *Boundary Layer Climates.* Methuen, London.

Parks and Wildlife Service Tasmania. 2000. *Tasmania's Wilderness World Heritage Area Essential Bushwalking Guide and Trip Planner.* Parks and Wildlife Service Tasmania, Hobart, Tasmania (Brochure).

Parks and Wildlife Service Tasmania. 2002; Overland Track, <http://www.overlandtrack.com.au/>

Parks and Wildlife Service Tasmania. 2005; Overland Track Statistics, <http://www.parks.tas.gov.au/manage/statistics/walkerstats/>
[31/01/06]

Reinthaler, F.F., Wust, G., Haas, D., Feierl, G., Ruckenbauer, G. and Marth, E. 2004, Simple emission-reducing measures in an open biological waste treatment plant, *Aerobiologia,* Vol. 00, pp.1-6.

Singley, J.E. 1971, Chemical and Physical Purification of Water and Wastewater, pp.365- 414 in Ciaccio, L.L. (ed), *Water and Water Pollution Handbook, Vol.1*, Marcel Dekker, Inc, New York, N.Y.

Stetzenbach, L.D. and Lighthart, B. 1994, *Distribution of bioaerosols*, pp.68-91 in Lighthart, B. and Mohr, A.J (eds), *Atmospheric Microbial Aerosols, Theory and Applications*. Chapman and Hall, New York, N.Y.

Stetzenbach, L.D. 2002, Introduction to Aerobiology, p.801-813 in Crawford, R.L., Hurst, C.J., Knudson, G.R., McInerney, M.J. and Stetzenbach, L.D. (eds), *Manual of Environmental Microbiology*, Second Edition, ASM Press, Washington, D.C.

Schwizer, B. and Davidson, L. 2001, *On-Site wastewater management technology in NSW: community and regulatory attitudes and practices*, in Proceedings of On-Site '01 Conference, 25-27 September, Armidale.

Appendix A. Human effluent loading approximation for The Overland Track.

An estimation of the human effluent output of walkers undertaking the Overland Track from Cradle Mountain to Lake St. Claire in Tasmania over the 2002 financial year.

Registered walkers 2002/3 fin. year = 8169 (NPWS, 2005)
Average time taken for Overland Track = 6 days (NPWS, 2002)
Average human urine output per day = 1.2 L (Del Porto and Steinfeld, 1999)
Average human faecal output per day = 150g (wet) (Del Porto and Steinfeld, 1999)

Walker days = registered walkers x average time taken = 49014 days

Total urine output = Average human urine output x walker days = 58816.8 L
Total faecal output = Average human faecal output x walker days = 7352.1 kg

Appendix B. Tipping bucket rain gauge capacity calculation

A calculation of the amount of water required to tip the tipping bucket rain gauge used for the purpose of measuring flow from the composting toilet facility to the Field Test Evaporator at Government Huts, Lake Dobson, Mt Field, Tasmania.

Diameter	= 145mm
1 tip	= .25mm over area of the gauge.
Area in metres	= πr^2
	= $\pi * 0.077^2$
	= .01862650284 m^2
Volume of 1 tip (L)	= .25 * .01862650284
	= 0.00465662571 L

Appendix C. Solar powered ventilator modification test

15/05/02

A test to determine the difference in performance elicited from the outlet gap and photovoltaic cells of the solar power ventilator being raised by 25mm over standard. A pair of identical anemometers was attached to a 100mm tube into which each solar ventilator was fitted. These were placed side by side and readings taken simultaneously with the photovoltaic cells aimed directly at the sun on a cloudless day with no wind. The test was repeated with the anemometers swapped to eliminate any difference in performance of the two.

Test One		
Reading	**Windspeed m/s^{-2}**	
	Modified	**Standard**
1	1.15	0.61
2	1.34	0.69
3	1.33	0.68
4	1.36	0.78
5	1.35	0.73
6	1.33	0.82
7	1.32	0.72
8	1.18	0.83
9	1.19	0.66
10	1.33	0.77

Test Two		
Reading	**Windspeed m/s^{-2}**	
	Modified	**Standard**
1	1.24	0.60
2	1.21	0.52
3	1.11	0.51
4	1.13	0.57
5	1.36	0.65
6	1.32	0.66
7	1.11	0.45
8	1.23	0.53
9	1.31	0.61
10	1.26	0.59

Average performance ratio Standard: Modified = 1.938:1 m/s^{-2}

Appendix D. Pointer accuracy test

24/08/01

A test to determine the accuracy of the galvanised steel pointer system utilized for measuring evaporation in the control and prototype evaporators over approximately 24 hour periods.

Reading number	**Amount removed (mL)**	**Amount returned (mL)**	**Difference**
1	57	44	13
2	61	71	-10
3	48.5	41.5	7
4	43	51	8
5	31	48	-17
6	43	51	-8
7	40	39	1
8	38	45	7
9	28	27.5	0
10	27.5	34	6
Average	41.7	45.2	0.7